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PHYSIOGRAPHIC HISTORY OF THE UPPER ARKANSAS AND EAGLE RIVERS, COLORADO[1]

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ABSTRACT

Along the Arkansas River in central Colorado, "high terraces" and "low terraces" are each divisible into two distinct levels. The uppermost terrace passes into rock-floored shoulders of the Mosquito and Sawatch ranges. It is not definitely assignable to glacial outwash and may represent the remnants of a stage of preglacial piedmont alluviation. The next lower terrace is outwash from early glaciers. The third is clearly the outwash from late (Wisconsin?) glaciers, and the lowest is outwash related to late recessional moraines. Lower alluvial terraces flanking the Arkansas from Hayden south are still later.

While the highest terrace material was being deposited in the Arkansas Valley, monoclinal shifting took place in the Eagle River valley, followed by down-cutting probably antedating glaciation.

The best-marked stage of earlier preglacial topography is recorded by isolated nearly flat rock floors at altitudes of about 12,000 feet.

Physiographic development consisted of: (1) uplift and mature dissection (Oligocene?); (2) uplift with rapid erosion (Terrace No. 1) (late Pliocene?); (3) glaciation with outwash (Terrace No. 2); (4) interglacial erosion; (5) renewed glaciation (Wisconsin?) with outwash (Terrace No. 3); (6) retreatal stage with outwash (Terrace No. 4); (7) postglacial processes. Stage 1 may represent the montane equivalent of the Rocky Mountain peneplain. The earlier Flattop erosion level of northern Colorado may be represented by the accordant summits of the Sawatch and Mosquito ranges.

EARLIER WORK[2]

The region to be discussed has been previously described by several geologists including members of the United States Geological

[1] Published by permission of the Director, U.S. Geol. Surv.

[2] S. F. Emmons, J. D. Irving, and G. F. Loughlin, "Geology and Ore Deposits of the Leadville Mining District, Colorado," *U. S. Geol. Surv. Prof. Paper 148*, pp. 1–20, 1927.

[Footnote continued on following page.]

Survey. A brief but pointed digest is presented by Fenneman,[3] and most recently Powers[4] has begun a study of and presented preliminary findings in the region to the south.

What is essayed in this paper is not an extensive revision of existing data, but rather a collection of the several details into a consistent picture of their development, for the purpose of correlation with other studies of the physiographic development in eastern and southwestern Colorado.

The writer's studies were carried on in connection with four summers of field work whose prime object was the areal mapping and economic study of the region surrounding the Leadville mining district on the west slope of the Mosquito Range. Reconnaissance trips were also made into nearby parts of Eagle, Gunnison, Lake, Park, Pitkin, and Summit counties, Colorado.[5]

Most of the altitudes cited were taken from topographic maps. In addition many, such as those given for the terraces, were obtained by hand level or aneroid.

OUTSTANDING PHYSIOGRAPHIC FEATURES OF THE REGION

The major topographic features of the region include two ranges, the valley that separates them, and the heads of drainage systems beyond the range crests (Fig. 1). The eastern mountains are the

R. D. Crawford and Russell Gibson, "Geology and Ore Deposits of the Red Cliff District, Colorado," *Colo. Geol. Surv. Bull. 30*, pp. 16–19, *loc. cit.*, 1925.

L. G. Westgate, "The Twin Lakes Glaciated Area, Colorado," *Jour. Geol.*, Vol. XIII (1905), pp. 285–312.

W. M. Davis, "Glaciation of the Sawatch Range, Colorado," *Harvard Bull. Mus. Comp. Zoöl.*, Vol. XLIX (1904), pp. 392–404.

S. R. Capps, Jr., "Pleistocene Geology of the Leadville Quadrangle, Colorado," *U. S. Geol. Surv. Bull. 386* (1909).

M. R. Campbell, "Guidebook of the Western United States—the Denver and Rio Grande Western Route," *U. S. Geol. Surv. Bull. 707* (1922), pp. 90–121.

B. S. Butler and J. W. Vanderwilt, "The Climax Molybdenum Deposit of Colorado," *Colo. Sci. Soc., Proc.*, Vol. XII (1931), pp. 314–16.

[3] N. M. Fenneman, *Physiography of the Western United States*, (New York: McGraw-Hill Book Co., 1931), pp. 92–132, esp. pp. 110–14.

[4] W. E. Powers, "Multiple Glaciation in the Sawatch Range, Colorado": *Geol. Soc. Amer., Bull.*, Vol. XLIV (1933), p. 210.

[5] Special thanks for various kindly suggestions are due to Messrs. G. F. Loughlin, B. S. Butler, W. C. Alden, and T. S. Lovering, of the United States Geological Survey; Professor J. Harlan Johnson, of the Colorado School of Mines; Professors W. E. Powers and J. T. Stark, of Northwestern University; and Professor N. M. Fenneman, of the University of Cincinnati.

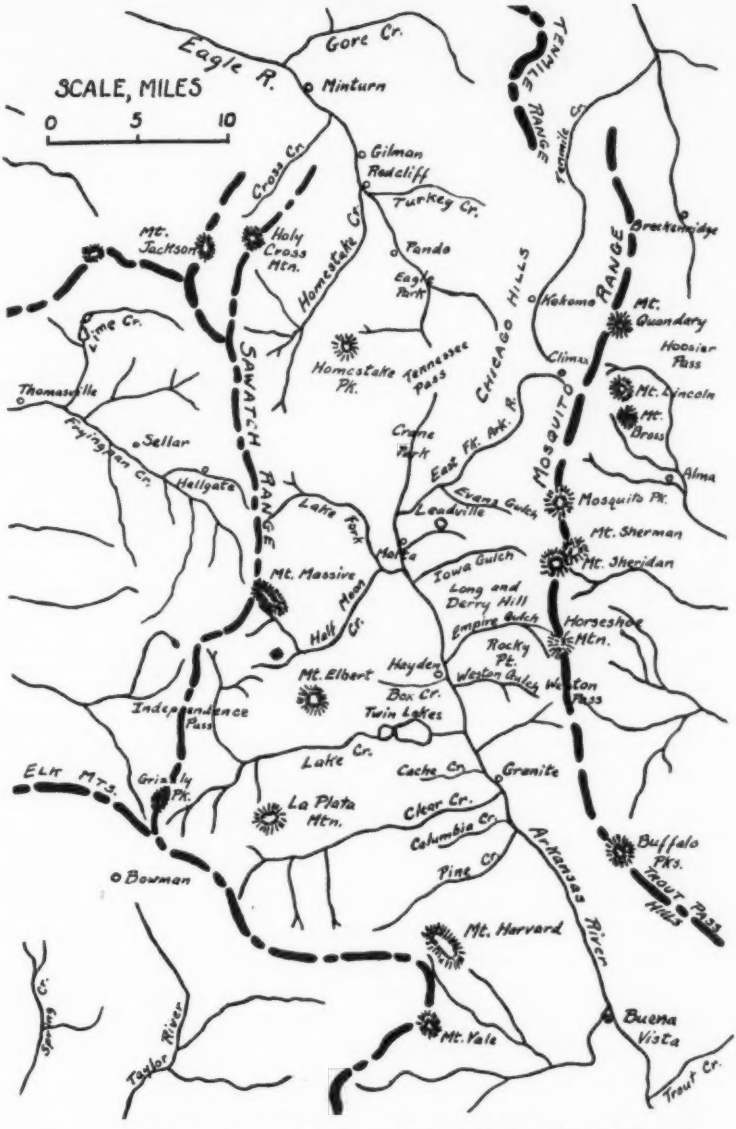

FIG. 1.—Sketch map of upper Arkansas and Eagle drainage and bordering ranges

Mosquito, or Park Range, which north of the headwaters of Tenmile Creek is also called the Tenmile Range. It includes several peaks with altitudes of 14,000 feet or more. It consists of a pre-Cambrian complex overlain by sedimentary rocks with a prevailing easterly dip. West of the Mosquito Range and rising to slightly higher altitudes, the maximum of which is approximately 14,400 feet, is the Sawatch, or Collegiate, Range. It consists chiefly of pre-Cambrian crystalline and Tertiary intrusive rocks. Both mountain ranges have been broken repeatedly by northerly trending normal and reverse faults, the eastern sides of which generally have been upthrown.

Between the two ranges is a broad valley with an average width of some 20 miles, measured from crest to crest of the bordering ranges. The valley bottom is about 5,000 feet below the range crests. Its southern part from the Eagle County–Lake County line southward is occupied by the southward flowing Arkansas River. The northern, more narrow part is drained by the northward flowing Eagle River. West of the crest of the Sawatch Range in the latitude of Leadville are the headwaters of the Fryingpan Creek. The headwaters of the Tenmile drainage rise on the west slope of the Mosquito Range and the main stream flows northward 10 miles east of the Eagle River, from which it is separated by the Chicago Hills; Tenmile Creek finally crosses the Tenmile-Mosquito Ranges about 20 miles north of the area here discussed (Fig. 1).[6]

The outstanding physiographic features are glacial cirques and glaciated valleys near the crests of the ranges, local high-level surfaces of conspicuous flatness, and, in the Arkansas Valley, flat mesa-like terrace forms. These conspicuous terraces lend to the upper Arkansas Valley a marked contrast with the valleys of the other main streams of the region. The upper part of the Arkansas flows in an exceptionally wide trough, whereas the other major streams mentioned occupy mostly V-shaped valleys or canyons of U-shaped cross section, of which the ratio of width to depth averages 5:1 or less. The upper Eagle Valley is wide but asymmetrical, the eastern slope being generally much steeper.

In view of the size of the area detailed descriptions of these several

[6] See also S. F. Emmons, "Geology and Mining Industry of Leadville," *U. S. Geol. Survey Mono. XII* (1886), Sheet V.

features are only given when it is necessary to supplement previous accounts in order to bear out new conclusions.

GLACIAL FEATURES

Moraines and stages.—Clearly there are conspicuous deposits made by two main glacial stages. The earlier one, recognized by Westgate and Capps, is only very locally preserved in the Sawatch and Mosquito ranges on account of the ravages of later erosion. Though generally useful, the criterion applied by Westgate and Capps for distinguishing these earlier glacial deposits, namely the

FIG. 2.—View down Empire Gulch, Mosquito Range, showing typical glaciated valley; Sawatch Range in distance.

far greater degree of weathering which they have suffered in comparison with the later moraines, can scarcely be regarded as infallible, because differences in the lithology of the glacial boulders affect so greatly the relative rapidity of decay. The existence of these early morainic deposits and the importance of this stage of glaciation in furnishing outwash, are not subject to question however.

A later glacial stage, generally regarded as the equivalent of the Wisconsin stage of the Mississippi River basin, has left widespread and more readily recognizable effects. In addition to having developed the cirques and U-shaped valleys now so conspicuous (Fig. 2), the ice of this stage deposited remarkable moraines at lower elevations. Examples may be seen at Twin Lakes, on Half Moon Creek, Lake Fork Creek, and most of the tributary gulches of the Arkansas,

as well as on Cross Creek, Homestake Creek, and most of the headwaters of the Eagle River.

One of the striking features is the relatively large size of some of the lateral moraines of this glacial stage in comparison with the size of the terminal moraines. For instance, the lateral moraines of the Homestake glacier rise in places several hundred feet above the valley floor, whereas the terminal moraine is a low ridge having a maximum height of only 40 feet. Such occurrences are usually confined to narrow valley mouths where the concentrated flow of water from the

FIG. 3.—Prominent double cirque at head of Dyer Amphitheater, 6 miles east of Leadville.

melting ice front washed away most of the drift. An additional factor favoring increase in height of lateral moraines is the banking-up of the drift against the valley slopes.

A detail of the later stage of glaciation, recognized but not discussed by Capps,[7] is the presence of distinct recessional moraines which appear in most of the valleys. Typical examples are seen 3 miles west of the mouth of Clear Creek, near the Vega Shaft in Evans Gulch, up Homestake Creek 2 miles north of Pando, and up the East Fork of the Arkansas 9½ miles from its mouth. Probably to be correlated with this halt in ice recession is the fact that almost all of the valley heads are characterized by double cirques (Fig. 3). Presumably the higher of such double cirques may represent a distinct

[7] *Op. cit.*, p. 14 and Plate I, up gulch west of Evergreen Lakes.

step in headward cutting by the glacier during a late substage in which the ice accumulation was not sufficient to carry the floor of the glacial valley at the head of the amphitheater to as great a depth as was attained in the earlier, more extensive substage. This feature is generally recognizable at the heads of prominently glaciated valleys. Its widespread occurrence in regions where the rocks are of uniform character and where both cirque floors show about the same degree of weathering indicates that the feature is assignable neither to differences in rock resistance to ice erosion nor to two glacial stages greatly separated in time.

Locally valley benches are found that suggest, but do not conclusively demonstrate, the former existence of higher U-shaped valleys, the remnants of whose floors remain as shoulders above the valley bottoms developed during the later glacial stage. These are frequently covered by the high-lying lateral moraines of the late glacial stage, but elsewhere the rock floors of the shoulders are visible. Thus on Clear Creek, about 2 miles south of Granite, a rock shoulder is exposed at an altitude of about 10,000 feet near the upper end of the reservoir. In Empire Gulch there is a similar bench at an altitude of 11,650 feet on the south slope of Long and Derry Hill. This bench is partly covered by a lateral moraine of later glaciation, but locally the rock crops out beneath the moraine and is exposed elsewhere in shallow prospect holes. On the southwest slope of Rocky Point at about 11,200 feet, another rock-floored bench is present (Fig. 4). The differences in the altitudes of such surfaces are obviously not significant, since all valley floors, whether glacial or stream worn, rise headward to differing elevations.

Drainage changes and local ponding induced by glaciation.—The drainage changes caused by the earlier glacial stage are no longer recognizable, but those due to the two subdivisions of the later stage are very well marked. One of the most striking of these is that at Pando, described and variously interpreted by Capps and Campbell.[8] On the southwest side of Eagle Park, about 4 miles south of Pando, a glacier occupying Eagle Park ponded the headwaters of the West Fork of Eagle River and that stream, filled with

[8] Capps, *op. cit.*, pp. 23–25, 34–35; Campbell, *op. cit.*, pp. 115–16; Crawford, *op. cit.*, p. 17.

glacial outwash, was thus forced to lay down, just north of the station of Mitchell, a valley train or delta composed of coarse gravel. South of Tennessee Pass, on the Arkansas, similar ponding and deposition took place, as at the southwest end of Crane Park, where recognized by Capps.[9] Glacial ponding behind morainic dams also took place in the present basins of Twin Lakes. The stream from the glacier in the last-named area probably swept for a time over the col now followed by the northeast road in crossing the northern edge of the moraine of Twin Lakes, and deposited at least a part of the

FIG. 4.—View west down Weston Gulch toward Sawatch Range. Shows rock terrace (slightly to left at center) on south slope of Rocky Point at altitude of 11,200 feet.

placer gravels on Derry Ranch 2 miles west of Hayden. This explanation accounts for the gold dredged from the Box Creek flats, as gold ores are not known to occur up Box Creek, whereas several large lodes have been discovered in the Lake Creek basin.[10]

Where the granite walls constrict the Arkansas Valley near the town of Granite, the large glacier from the Sawatch Range, locally crossing the axis of the Arkansas valley, forced the river against the east valley side. The Arkansas thus came to be flanked in many places by steadily renewed ice or morainic material on the west and by hard granite on the east, a fact which probably contributed to the development of certain rock terraces (for example, part of Terrace No. 3, discussed on the following pages) in the valley of the main

[9] *Op. cit.*, pp. 23, 38.

[10] E. P. Chapman, oral communication, 1930.

stream. Such a relation is still well indicated at the mouth of Clear Creek and better yet south of Columbia Creek, where steeply dipping silt beds, deposited behind the morainic dam, appear in a highway cut.

On Fryingpan Creek drainage changes, as far as studied, are most conspicuous in the tributary valleys of the main stream. Many of these small valleys harbored only small ice tongues or *névé* in glacial times, whereas the Fryingpan glacier built huge lateral moraines to a height of 900 feet above the present valley floor. These lateral

FIG. 5.—Lateral moraine (timbered ridge in middle distance) and filled preglacial hanging valley (foreground) on Fryingpan Creek, between Sellar and Hellgate. The floor of the main valley, out of view between the moraine and distant hills, is 900 feet below the crest of the moraine.

moraines ponded the small, ice-free, preglacial valleys which then became silted up behind the morainic ridges. Two excellent illustrations of such features are crossed by the highway at altitudes of about 9,650 feet between Hellgate and Sellar, Mt. Jackon quadrangle (Fig. 5).

TERRACES OF THE ARKANSAS VALLEY

The terrace-like forms in the Arkansas Valley are made conspicuous there through the absence of other topographic features that would tend to dwarf them. These terraces were studied by West-

gate[11] and by Capps. Capps classified them into two groups—"high level" and "low level" terraces. A closer study, however, shows

FIG. 6.—View east across Arkansas valley toward Terrace No. 1 about 2 miles south of Leadville. Mosquito Range in distance. The appearance of an abrupt rise at the head of the terrace is illusory and due to timber distribution.

FIG. 7.—View looking south from Capitol Hill, Leadville. Shows high terraces which grade into bedrock slope in the wooded area at left without perceptible change.

that each group is subject to a further division—a fact recognized though not fully developed by Capps[12] and first suggested to the

[11] *Op. cit.*, pp. 288–89. [12] *Op. cit.*, pp. 62–63.

writer by T. S. Lovering. The writer now distinguishes five major groups of terraces above Granite:

Terrace No. 1 ("high level" of Capps in part)
Terrace No. 2 ("high level" of Capps in part)
Terrace No. 3 ("low level" of Capps in part)
Terrace No. 4 ("low level" of Capps in part)
Terrace No. 5 (postglacial)("low level" of Capps in part)

Terrace No. 1.—The highest terraces are best seen on the east side of the Arkansas Valley between Malta (Leadville sheet) and the mouth of Weston (Big Union) Gulch. At Malta they have altitudes

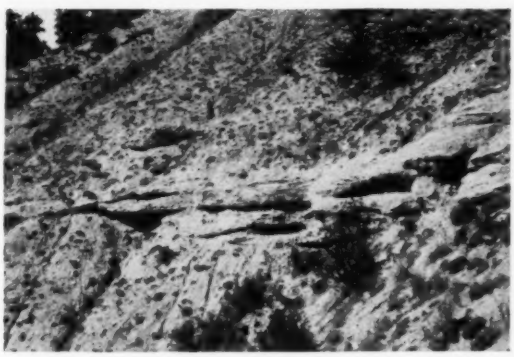

FIG. 8.—Indurated gravel beds of Terrace No. 1 near mouth of Weston Gulch about 7 miles south of Leadville.

of about 10,050 feet and at the mouth of Weston Gulch, 9,750 feet, or 360 feet above river level. These altitudes are approximate only and represent measurements made nearest the axis of the Arkansas Valley. An average of several slope profiles gives about $2\frac{1}{2}°$ near the valley axis, but there is gradual steepening toward the mountains (Figs. 6 and 7). At the mouth of Weston Gulch dissection has reduced the flat, mesa-like terrace surfaces to saw-tooth ridges. They are composed of gravel and sand in irregular, discontinuous laminations or beds and are generally well cemented (Fig. 8). Individual boulders, especially those of limestone and igneous rock, are moderately decayed. The fragments are well rounded and vary in size from fine sand grains to cobbles 2 feet in diameter. No striated

or clearly faceted boulders were found. Beneath these deposits and exposed only in shafts and borings near Leadville and in the flat at the mouth of Weston Gulch are local sediments that are fine grained and in places marly. It is these sediments in part to which the term "lake beds" was applied by Emmons and his associates.[13] The explanation of these beds, apparently representing Tertiary sedimentation in local basins, is not attempted in this paper, as they are only very poorly and inadequately exposed.

No bed rock close to the surface has been discovered, by means of shafts, near the axis of the Arkansas Valley and north of the mouth of Weston Gulch. The valleyward part of this set of terraces may therefore be regarded as the result of aggradation. Followed eastward up the slope of the Mosquito Range the alluvial deposits forming the terrace surface gradually become thinner and finally disappear and the surface is on a rock slope or piedmont essentially continuous with the alluvial surface. The alluvium of the high terrace has been stripped from most of the west side of the Arkansas Valley, but remnants of the rock pediment which represents its mountainward continuation are still visible. Downstream, also, this terrace level is represented chiefly by a dissected rock bench. From the mouth of Weston Gulch southward the high terrace level appears on the east side of Arkansas River mainly as a much dissected, sloping, rock floor only slightly lower than the altitude characteristic farther north. On the east side of Arkansas River, opposite the mouth of Clear Creek, are two prominent notches in flat-topped rock shoulders projecting into the valley. The lower of these notches may represent the location of the old river bed, corresponding to or antedating the highest terrace level here described (Fig. 9). From Clear Creek south the highest terrace is apparently represented at high altitudes by a bench developed on the pre-Cambrian rocks of the west slope of the Mosquito Range, sloping gently southward at about 20 feet per mile, and greatly dissected. A suggestion of the same terrace is visible at altitudes of about 9,800 feet south of Trout Creek in the Trout Pass Hills.

Even where best developed the alluvial facies of this terrace

[13] "Geology and Ore Deposits of the Leadville Mining District, Colorado," *op. cit.*, pp. 17–20.

level is notably dissected. It is scarcely visible at all on the east slope of the Sawatch Range and on the opposite side of the Arkansas Valley every small stream which flows across it has entrenched itself to several hundred feet. These trenches are in many places occupied by glacial moraines of distinctly later age. An excellent example of such relationship is seen at the mouth of Weston Gulch where the numerous lakes of the Mount Massive Trout Club occupy kettles

FIG. 9.—View east across Clear Creek reservoir, showing east slope of Arkansas valley with two rock-floored notches at 10,000 (at left) and 9,500 feet (in middle) respectively.

in typical morainic topography which lies 100 feet or more below the terrace crests to the north and south.

Discussion of the origin of these terraces is deferred to page 799.

Terrace No. 2.—The next lower group of terraces is best represented between Half Moon and Box creeks. Here the altitude is approximately 9,610 feet where its remnants appear nearest to the valley axis, or about 220 feet above river level, and 140 feet below Terrace No. 1. Toward the mountains its slope ranges from 2° upward.

This terrace and Terrace No. 1 have been thought by earlier workers to represent one and the same stage of development. The confusion is not surprising, because it is only near the valley axis that the two are readily distinguishable. As the crests of the ranges are approached, the surfaces of Terrace No. 1 and Terrace No. 2

merge into each other and are not separable. It is probable, however, that the greater part of the terrace remnants at high elevations belong to Terrace No. 1. A significant fact is the common occurrence of Terrace No. 2 in association with morainic material of the early glaciers, as clearly recognized by Westgate,[14] who, however, did not discuss the difference in altitude of the two terraces.

The area between Half Moon and Box creeks is regarded as the type locality for the No. 2 terrace. Its wide alluvial flats extend from the south edge of the terminal moraine of Half Moon Gulch south to the prominent moraine at the northeast end of Twin Lakes. It is evident that the moraine of Half Moon Gulch, a product of late glaciation, lies on top of and hence is later than this terrace. The late glacial moraine of Twin Lakes is also superimposed upon Terrace No. 2. It was thought by Westgate to extend over the eroded edge of this terrace and down into the Arkansas Valley,[15] but Westgate's "moraine" is more plausibly assigned to landslides. On this west side of the Arkansas the rock floor of this terrace, though generally covered by alluvial material, is locally exposed at the same elevation as its counterpart east of the river. When deposition of the gravel that makes up Terrace No. 2 began, the channel of the Arkansas River probably lay close against the bedrock slope of the Sawatch Range. The gradual filling up of the old channel finally raised the stream to the level of the top of the rock surface farther east and the river was shifted approximately to its present position where it then cut the granite gorge in which it now flows.[16]

Upstream from Half Moon Gulch this terrace is hidden under the late glacial and glaciofluvial deposits of Lake Fork and is not recognizable. Southward it is probably represented by a relatively flat surface appearing intermittently west of the Arkansas, as near the mouth of Pine Creek.

Origin of high-level terraces.—Westgate interpreted the gravel composing Terrace No. 2 as glacial outwash deposited at the earlier of the two stages of glaciation—when the older terminal moraines, with which the terrace is in places seen to be continuous, were formed. This interpretation is unquestionably correct.

[14] *Op. cit.*, p. 289 and Fig. 3.

[15] *Ibid.*, p. 286 and Fig. 1.

[16] Capps, *op. cit.*, Fig. 1.

Near the axis of the Arkansas Valley, Terrace No. 1 is also cut by valleys in which there was late glaciation. Higher on the mountain slopes it is surmounted in many places by the terminal moraines of the late glacial stage (for example, on Lower Long and Derry Hill, 4 miles southeast of Leadville). It thus clearly antedates the later of the two major glaciations.

Emmons' earlier interpretation of Terrace No. 1 as lake beds may be dismissed as no longer tenable. Capps[17] first suggested that this terrace was of glaciofluvial origin, but regarded it as coextensive with Terrace No. 2. As evidence of the glacial origin of this terrace, Capps cited the occurrence of the older drift near and indeed just below this terrace, in one locality "two miles west of Leadville." No details of this occurrence were given, and anyone acquainted with the unsatisfactory records of mines and prospects when surface "wash" is described will feel (1) a justifiable doubt that till is actually known to underlie the high-level gravels and (2) a further uncertainty that the subjacent material, even if it be till, is to be correlated with the earlier moraines of Westgate and Capps. Indeed, the picture gained from an attempted reconstruction of the original distribution of these highest gravels is rather one of a group of coalescing piedmont alluvial fans than of a group of valley trains uniting as they approach the center of the Arkansas Valley. Were the latter the correct explanation there should be areas virtually free from glaciofluvial deposits between the valleys which were occupied by the ice tongues of earlier glaciation, and the outwash should end against moraines or should at least locally extend up the tributary valleys.

A second difficulty facing Capps's interpretation arises from the fact that at the mouth of Lake Creek, where the terminal moraine of the older glaciation has been carefully studied, the terrace level of known outwash from this older moraine has an altitude approximately 140 feet below Terrace No. 1, as seen across the Arkansas Valley. In this region both terraces slope toward the valley axis at about 2°—hence would seem to be about equidistant from the axes of those stages of the Arkansas River existing at the time when they were formed. If the two levels represent parts of the same alluvial

[17] *Ibid.*, p. 17.

valley and the west terrace owes its lower elevation to its more nearly median position with respect to the valley axis, that terrace surface should have a flatter slope. It appears, therefore, that we are dealing with two distinct and clearly separable terrace levels. Terrace No. 1 thus represents an enormous amount of alluviation probably not connected with the formation of the oldest moraines now visible in the upper Arkansas and greatly exceeding in quantity the alluviation assigned to any recognized glaciation in this region.

Neither of the lines of evidence given above may be regarded as conclusive proof that Terrace No. 1 was not formed from glacial outwash, but they at least weaken the justification of the assumption that it was so formed. It is of course possible that the drift described by Capps as occurring in the prospect pit 2 miles west of Leadville is from a still earlier, but hitherto undemonstrated glacial stage. The inference is strengthened by the fact that Powers[18] has found three distinct glaciofluvial terraces near Buena Vista, of which the uppermost may represent the downstream continuation of Terrace No. 1. The isolated boulders on the east side of the Arkansas near Granite, cited by Capps[19] as evidence for a third, still earlier glacial stage, may point to the same conclusion. With respect to these boulders, however, it is at least equally probable that they date back to an early high-level channel of the Arkansas, topographic remnants of which have been found in the same locality as already mentioned.

A second, equally plausible explanation for Terrace No. 1 may now be offered. Previous to the Pliocene uplift, the effects of which are generally recognized in the southern Rocky Mountains, erosion may be supposed to have progressed to the stage of maturity and the definitive Arkansas Valley perhaps dates back to that time. This pre-Pliocene erosion will be discussed on a following page. After the Pliocene uplift erosion was greatly stimulated and the mountain slopes especially were subjected to rapid wearing away. At any given time there would be an abrupt change in gradient marking the head of the region cut by rejuvenation. This abrupt change in slope would be gradually shifted headward toward the crest of the range from the valley axis. Erosion at the point of topographic discord-

[18] Oral communication, 1932.

[19] *Op. cit.*, p. 15.

ance would produce sapping and an overloading of the lower parts of the rejuvenated streams, so that sheetlike gravel deposits accumulated in the valleys as well as on the slopes between the valleys. The process would be still more favored by aridity such as has been inferred from earlier studies[20] in this and nearby regions. A gravel-covered piedmont alluvial plain would thus result. Such fans, growing steadily headward, would finally cover the newly cut slopes. This interpretation differs little from that of Capps[21] except that glaciation is not required.

By way of comparison with southwestern Colorado, the reader is referred to the description by Atwood and Mather of high-level mesas in the San Juan region, which clearly resembles that already given for Terrace No. 1 of the upper Arkansas. Atwood and Mather recognize three Pleistocene glacial stages of which the later two are apparently to be correlated with the two main stages described in this paper. Extensive mesa-like gravel terraces, similar to Terrace No. 1 in the Arkansas Valley, are thought to be alluvial deposits laid down "some time after the retreat" of the earliest glacier or possibly while the earliest glaciation was still in progress.[22] The authors also recognize earlier alluvial deposits of various degrees of coarseness which antedate the outwash just mentioned and are attributed to alluviation following uplift just before the beginning of the Pleistocene.[23] It is as yet not certain whether the gravels of Terrace No. 1 are to be correlated with the earliest glacial or the still earlier, preglacial gravels of the San Juan region.

Terrace No. 3.—This terrace is best seen northeast of the crescentic terminal moraine at the mouth of Half Moon Gulch, where its lower edge is about 30 feet above the present level of the Arkansas River or 190 feet below Terrace No. 2 and 330 feet below Terrace No. 1. The gradient is less than that of the stream. Upstream it can be followed to the moraine of Lake Fork Valley. Below Twin Lakes traces of this terrace level are preserved only at intervals. Westgate

[20] Emmons, Irving and Loughlin, *op. cit.*, p. 272; T. S. Lovering, "Geologic History of the Front Range, Colorado," *Colo. Sci. Soc., Proc.*, Vol. XII (1929), p. 103.

[21] *Op. cit.*, pp. 16–17.

[22] W. W. Atwood and K. F. Mather, "Physiography and Quaternary Geology of the San Juan Mountains, Colorado," *U. S. Geol. Surv. Prof. Paper 166* (1932), pp. 111–19.

[23] *Ibid.*, pp. 84–101.

assigns some of the terraces in the river bottom to this series.[24] The writer believes that the level here lies somewhat higher than that recognized by Westgate and is represented by the wash at the mouth of Box Creek and the lower terrace on which the Cache Creek placer gravels are developed.

The boulders in Terrace No. 3 are well rounded and moderately well sorted. Striated and faceted individuals are rare, but the equivalent gravels at the mouth of Evans Gulch at Leadville show some glacial boulders. The gravels of this group are generally much less decayed than any of the older gravels.

These gravels are clearly derived from the terminal moraines of the later of the two well-marked glacial stages recognized in this region. This fact is amply demonstrated by their occurrence immediately in front of the terminal moraines of Lake Fork, Half Moon Gulch, the East Fork of Arkansas River, and Evans Gulch. They represent valley trains or outwash aprons of the farthest advance of the last glacial ice.

Terrace No. 4.—This low terrace appears not to be well marked in the Arkansas Valley, but shows clearly in many of the tributary valleys. Remnants are well preserved east of the Eagle River highway bridge on the East Fork of Arkansas River, and surrounding the Clear Creek Reservoir where the terrace is mapped by Capps as lake beds.[25] Its surface is generally 20 or 30 feet above the present water level in the tributary valleys. The close association with small recessional moraines strongly suggests outwash from a halt in the last glacial stage.

Terrace No. 5.—Strictly speaking, this term is here applied to a group rather than to a single terrace. Near the mouth of Weston Gulch a low terrace appears, 8 feet above the level of the Arkansas, and this terrace is distinct northward as far as the terminal moraine of Lake Fork Valley, due west of Leadville. On the Arkansas the highest and oldest of this late group of terraces is well developed about 2 miles below Granite at an altitude of approximately 9100 feet, though traces appear as rock-floored surfaces between Granite and the mouth of Lake Creek. South of Granite it is clearly alluvial and the well-stratified material which composes it is very poorly ce-

[24] *Op. cit.*, Fig. 1 ("Later gravels") and p. 299. [25] *Op. cit.*, Pl. I.

mented. About 1 mile south of the mouth of Columbia Creek is a rock terrace having an altitude of approximately 8,900 feet, or about 30 feet above river level. This may well represent the same terrace level. From their relations to the present river level the conclusion seems warranted that these several remnants were originally parts of one and the same feature.

Such terraces, on account of their slight elevations above the streams and their apparent postglacial age, have been studied only cursorily. They are thought to mark minor states of erosion in the cutting of the gorge of the Arkansas below Salida.

Summary of terrace history.—The history of the upper Arkansas, as far as the terraces give evidence, may now be correlated in part with what has already been said about glaciation. This gives the following sequence of events:

1. Alluviation, resulting either from an early glaciation whose moraines are now covered or obliterated, or more probably from a period of fan-building following uplift and probable aridity and preceding glaciation; this gave the gravel deposits now preserved in Terrace No. 1
2. A period of erosion
3. Glaciation and deposition of outwash gravel comprising Terrace No. 2
4. An interglacial period of erosion in which much of Terrace No. 2 was cut away
5. Glaciation, and deposition of gravel comprising Terrace No. 3
6. Retreat of ice fronts and formation of recessional moraines and low outwash terraces (No. 4)
7. Beginning of postglacial time punctuated with alluviation and the formation of low terraces (No. 5)

GLACIAL AND LATE PREGLACIAL HISTORY OF UPPER EAGLE VALLEY

While the notable terrace deposits described above mark several of the physiographic stages in the Arkansas Valley, the contemporaneous history of the Eagle River Valley is not so clear. From Minturn upstream to within 2 miles of Tennessee Pass the remnants of earlier topography point to monoclinal shifting of Eagle River as the dominant preglacial process. This shifting was eastward upon the hard floor of the Cambrian quartzite or along the top of the underlying pre-Cambrian rocks—thus giving in large part an exhumed pre-Paleozoic erosion surface, and continuing in part even to modern

times in the undercutting of the late Carboniferous beds on the northeast side of the valley between Minturn and Gilman (Figs. 10 and 11). The main monoclinal shifting on the upper Eagle River

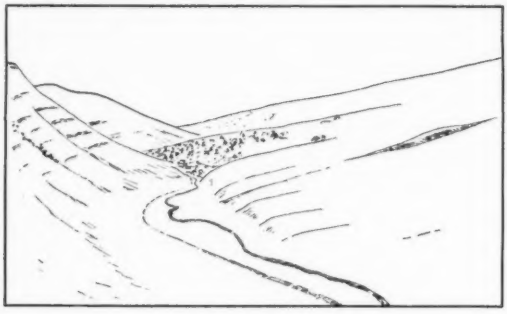

FIG. 10.—Sketch of view south up Eagle River from Minturn, showing monoclinal slope to right and undercut cliffs of late Carboniferous rocks to left.

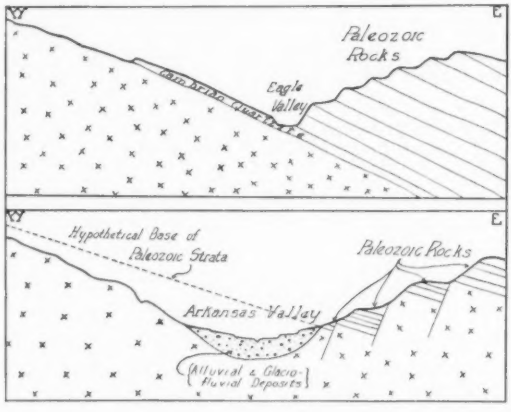

FIG. 11.—Generalized section across Eagle River at Pando (above) and across Arkansas River at Leadville (below), to show contrast in larger structural features.

apparently coincided in general with the building of the highest alluvial terrace (Terrace No. 1) on the upper Arkansas as described on page 800. The basis for such correlation is the actual similarity in

the two processes as well as the time relation between the earlier monoclinal valley of the upper Eagle River and the erosive effects of the earlier of the two recognizable glacial stages in this region.

The contrast between the preglacial histories of the Arkansas and of the Eagle, as just outlined, may best be ascribed to differences in the relations between the two master streams and the crystalline rocks on which they flow (Fig. 11). It may be remarked parenthetically that there are good reasons for believing that the entire Eagle Valley above Minturn is much younger than that of the upper Arkansas. On the Arkansas, because of the greater relative uplift, the main preglacial valley had been cut well down into the more homogeneous pre-Cambrian rocks; erosion was controlled mainly by minor, irregular structures within the pre-Cambrian complex, or by fault planes extending northward on the west flank of the Mosquito Range, or else erosion was essentially independent of structure. In contrast, the Eagle above Minturn has cut down to the pre-Cambrian mainly in glacial and postglacial times, and thus until very recently any temporary alluvial deposits on the east bank were constantly subjected to erosion. Such alluvial deposits as may have been left along the western or dip slope on the divides between the easterly flowing tributaries of the Eagle were largely incorporated in or concealed by subsequent glacial and glaciofluvial deposits from the crest of the Sawatch Range and are thus not recognizable today. If prominent glaciers had occupied the divide between the Eagle and Gore Creek, their outwash might have shielded the east slope or even have filled the Eagle Valley, giving it a width and terraced appearance similar to the upper Arkansas.

The coincidence of the west slope of Eagle Valley with the dip of the Cambrian quartzite is most readily recognized in a view up the valley from Minturn (Fig. 10), but remnants of the dip slope may be seen west of Eagle Park (Fig. 12). There it is evident that the western slope of the erstwhile monoclinal valley was cut into at some time and then widened by glaciation and the erosive action of the stream was thus brought to bear upon the pre-Cambrian. At sometime before this trenching of the monoclinal slope, however, there was a stage of valley broadening indicated by a rock bench about 300 feet above the present river level and visible above Redcliff on the Eagle

and on Turkey and Homestake creeks (Minturn quadrangle) and preserved as flat-topped spurs between Redcliff and Gilman on the east valley wall of Eagle Valley. It is not known, however, whether this level marks a pause in erosion or represents a relic of the wider, early glacial valley bottom.

This question is linked with the more important one—was the trenching of the monoclinal slope forming the western wall of the preglacial Eagle Valley due to a preglacial uplift and consequent accelerated stream erosion, or to a similar process between glacial stages, or to trenching initiated by the ice itself at either glacial

FIG. 12.—Looking north down Eagle Park. The slope to the left is on the east-dipping Cambrian quartzite. The valley is a silted-up glacial trough.

stage? The facts bearing on the answer may at least be summarized, even though they are by no means conclusive.

From Pando north the Eagle flows in a narrow gorge. About 4 miles below Red Cliff, however, the valley widens and the stream gradient declines notably. In the valley of the Eagle near the place where this change occurs, at the mouth of Cross Creek, Campbell has recognized two morainic ridges crowding the Eagle against its northeast bank. He has inferred that one of these moraines is distinctly older than the other[26] and hence it is probably attributable to the earlier of the two glacial stages recognized in the upper Arkansas Valley. This conclusion, coupled with the fact that the valley here

[26] Campbell, *op. cit.*, p. 120.

preserves its broad, monoclinal form, strongly points to the preglacial age of this part of the Eagle Valley.

Due west of Gilman two small valleys west of and tributary to the Eagle lie side by side, separated only by a narrow ridge and emptying directly into the Eagle River canyon. The more northerly, which now carries a rushing stream, empties into the Eagle without falls and is thus clearly in accord with the present cycle. The more southerly tributary valley, however, has a wider floor and discharges well up on the canyon wall, but still below the topmost cliffs of the canyon rim; it is thus clearly not in accord with the present valley level of the Eagle and is interpreted as of late glacial or earlier age. Moreover, as already noted, Eagle Park at Pando and the lower Homestake Valley 3 miles above Red Cliff, both contain glacial deposits. In view of these facts the conclusion seems justified that the higher, flat-topped spurs between Red Cliff and Gilman, and those parts of the Eagle Valley which cut the dip slope of the pre-Cambrian antedated at least the later glaciation. All of these facts, however, simply confirm the existence of the Homestake Valley and upper Eagle Valley (excepting only that section between Pando and Red Cliff) in time preceding the latest distinct glaciation.

The lower part of the present Homestake Valley from 2 miles below Pando northward, shows no evidence of glacial erosion. This part of the valley is cut through the monoclinally dipping Cambrian quartzite; whatever explanation is urged to account for the trenching through the monocline at Eagle Park, therefore, must also have operated at Gilman, where glaciation was never effective. Taking all of these facts into consideration, it seems most probable that the cause for the trenching through the monocline was a late Pliocene or early Pleistocene uplift and that the upper reaches of the Eagle Valley, such as Eagle Park, which now show U-shaped sections suggestive of glaciation, were carved in preglacial times, and merely modified by glacial erosion. In face of a tendency, then already well developed, to slip off along a monoclinal dip, the Eagle-Homestake drainage must have suffered very rapid uplift and acceleration to bring about down-cutting in place of monoclinal shifting.

It would seem, therefore, that during the time that intervened between the deposition of the highest terrace gravel (No. 1) in the

Arkansas Valley and that of the deposition of the material now making up Terrace No. 2, the Eagle River was rapidly cutting downward instead of shifting monoclinally eastward as formerly. The existence of a period of erosion probably due to uplift is therefore inferred and the histories of the two valleys appear to be brought into accordance with each other.

EARLIER PHYSIOGRAPHIC HISTORY OF THE REGION

A 12,000-foot erosion surface.—The preceding discussion has dealt with the record furnished by terraces, rock benches of low altitude,

FIG. 13.—High-level surface at an altitude of 12,300 feet near Buffalo Peaks. Weston Peak (at right, distance) is in the Mosquito Range.

and definitely glacial features. The still earlier physiographic history is written in purely erosional land forms which are perserved only in the higher parts of the region. The outstanding observation not hitherto reported in print is a fairly continuous surface or bench of low relief above which rise the higher peaks of the two main ranges.

Some of the localities where this high erosion surface is still well preserved may be mentioned. Little Ellen Hill 4 miles east of Leadville is a remnant of the surface. On the ridge northeast of Buffalo Peaks and south of Weston Pass at an altitude of 12,300 feet there is a remarkably flat surface about 4 square miles in area (Fig. 13)

which is suggested on the map of the Hayden Survey.[27] At the crest of the Mosquito Range near Weston Pass, and ranging from 11,500 to 12,000 feet in altitude, there is a flat surface that is probably of similar origin; it is cut by cirques of the later stage of glaciation. On the west slope of Mt. Massive prominent timber-covered benches are seen at 12,000 feet in several different places and on the Chicago Hills, which include Mt. Zion, about 4 miles north of Leadville, a similar surface appears as an especially conspicuous flat at an altitude of 12,100 feet (Fig. 14). On the lower part of the upper Eagle Valley its equivalent seems to be the divide between Eagle

FIG. 14.—View of Chicago Hills from west slope of Corinne Mountain. The nearly flat crest has an average altitude of 12,100 feet. Far beyond are the peaks of the Sawatch Range.

River and Gore Creek, but it is ill defined at best. In the upper part of Taylor Park, Gunnison County, there are also large remnants of this surface, rock floored, trenched by Taylor River, and maintaining as elsewhere, a singularly uniform altitude of about 12,000 feet (Fig. 15). Perhaps some of the most striking evidence occurs where benches are developed corresponding to this surface on the sides of the wider valleys. Thus, a very well-marked bench at an altitude of about 12,000 feet on the west slope of Hoosier Ridge north of Hoosier Pass and 6 miles south of Breckenridge (Leadville quadrangle) is probably part of the same general surface. On Clear Creek near its

[27] *U. S. Geol. and Geog. Surv. Terr., Colo. Atlas* (1877), Sheet VII.

head, 7 miles southwest of Twin Lakes, there are prominent spurs now deeply trenched by glacial valleys. A similar surface shows at an altitude of about 12,000 feet on many spurs above the North Fork of Lake Creek near Lackawanna Gulch and Independence Pass. At 11,850 feet on both sides of Tenmile Creek Valley near Copper Mountain, 4 miles north of Kokomo, there are similar wide benches a mile and a half apart. The erstwhile valley of which these were parts of the floor is far too wide and too deep to be explained by glaciation alone. Below this high-level surface the U-shaped, glacial valley of the Tenmile forms a narrow trench.

FIG. 15.—The gently rolling 12,000-foot surface in upper Taylor Park. The gorge of Taylor River lies between the nearer part of this surface and the distant Sawatch Range.

These data seem to point to an erosion cycle carried to maturity before the deposition of the gravels of Terrace No. 1. The broadness of the valleys, when restored, precludes the possibility that the streams were deeply trenched and the gently rolling topography of the valley bottoms favors the idea that erosion had already reached the mature stage. The general level of valley erosion must have corresponded to the 12,000-foot level, but exact correspondence is not to be sought, because the cycle had not passed the mature stage. What the topography actually looked like when the cycle was brought to a close is uncertain. The relief at the end of the cycle was approximately 2,000 feet and the total of glacial, interglacial, and

post-glacial trenching since that time is represented by an equal figure.

Correlation of the 12,000-foot surface.—On the basis of these data, the correlation of the high erosion surface just described with similar surfaces elsewhere in Colorado may be attempted. Only four recent papers need be mentioned as they combine all the data now available. Lee[28] called attention to two "peneplains"— the "Flattop" and "Rocky Mountain," in the northern part of the state, and gave their altitudes as 11,500 and 10,000 feet, respectively. The times of their development were not definitely stated. Lee, however, indicated the improbability that the Flattop peneplain was formed before the end of the Eocene or later than the Pliocene, and he suggested that erosion forming the Rocky Mountain peneplain furnished the material for the late Tertiary beds of the plains to the east. Richardson concluded that the lower, at least, of the two peneplains mentioned could also be recognized in the region around Pikes Peak,[29] though its altitude there was about 9,500–9,000 feet, and that the upper surface in that region might be represented by the crests of the higher peaks of the Front Range. Lovering and Van Tuyl have recently described four recognizable erosion surfaces whose names, approximate elevations in the center of the Front Range in northern Colorado, and ages are as follows:[30] Flattop, (11,500–13,000 feet, early Eocene), Medicine Bow (10,000–11,000 feet, late Eocene), Rocky Mountain (8,500 feet, Oligocene or early Miocene), and Mount Morrison (average altitude not given, Pliocene). The last named is little more than a bench. Aside from dating, still somewhat uncertain, the essential difference between the work of Lovering and Van Tuyl and that of Lee is the recognition of an important peri-

[28] W. T. Lee, "Peneplains of the Front Range and Rocky Mountain National Park, Colorado," *U. S. Geol. Surv. Bull. 730*, (1923), pp. 4–5, 15.

[29] G. B. Richardson, "Castle Rock Folio," *U. S. Geol. Surv. Folio No. 198* (1915), pp. 1, 12; G. I. Findlay, "Colorado Springs Folio," *U. S. Geol. Surv. Folio No. 203* (1916), p. 2.

[30] F. M. Van Tuyl and T. S. Lovering, "A Contribution to the Cenozoic History of the Front Range, Colorado," *Geol. Soc. Amer. Bull.*, Vol. XLIII (1932), p. 170; Lovering, oral communication; Van Tuyl and J. M. Coke, "The Late Tertiary Physiographic History of the High Plains of Colorado and New Mexico," *Colo. Sci. Soc. Proc.*, Vol. XIII (1932), pp. 19–25.

od of erosion between the Rocky Mountain and Flattop levels. Very recent studies by Van Tuyl and Lovering, not yet presented in print, are leading to further modifications of their views by these two authors.

It seems probable that the 12,000-foot erosion level of the Arkansas Valley region is the equivalent of the Rocky Mountain peneplain. The similarity between the 12,000-foot surface and the Rocky Mountain peneplain in the type locality as to relations with recognizable glacial features and as to the approximate extent and degree of maturity (with certain differences), as well as the fact that both were clearly developed much later than the Laramide disturbance, suggest this as the most plausible correlation. The altitude of the 12,000-foot surface along the Arkansas Valley is greater than that of the Rocky Mountain peneplain in the nearest regions where the latter has been recognized. This difference in altitude, however, is to be expected if the 12,000-foot surface represents the floors of mature valleys that are the western intermontane equivalents of the much more extensive Rocky Mountain peneplain as recognized in the Front Range.

A possible higher erosion surface.—A thoughtful observer will ask whether any remnants of still higher surfaces may be identified that might be correlated with the earlier peneplains of the Front Range. In reply, though the evidence is as yet not conclusive, the writer, following Fenneman,[31] calls attention to the surprisingly accordant peaks of the Sawatch Range (see the Leadville topographic sheet). The feature is all the more striking when it is noted that the highest points do not lie at the middle of the range, but on spurs extending out toward the flanking valleys. These highest summits, approximately 14,000 feet in altitude, may perhaps represent a yet earlier but much dissected erosion surface. Whether, if such a surface is hypothesized, it is to be correlated with either of the two peneplains recognized as preceding the Rocky Mountain level cannot as yet be stated.

It seems to the writer that the application of the term peneplain to any of the surface remnants described in this paper would be entirely misleading. The present isolated table-lands are too badly

[31] N. M. Fenneman, *op. cit.*, p. 114.

dissected or too limited in extent to furnish clear-cut evidence that they had attained the degree of baseleveling for which the term peneplain should correctly be reserved.

SUMMARY OF PHYSIOGRAPHIC HISTORY

What follows is based on the preceding generalizations and on the known bedrock geology as studied especially at Leadville and Redcliff. Early in the Tertiary folding and faulting took place, accompanied in its first stages by the intrusion of sills and dikes and in the latter stages by igneous injections more stocklike in form. The time of this period of intrusion and deformation is generally thought to

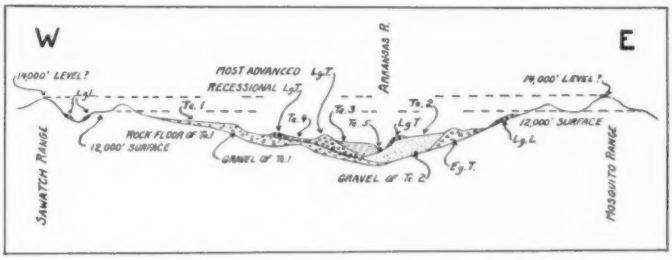

FIG. 16.—Diagram showing relations of more important physiographic features in the region. *T*, terminal moraine; *L*, lateral moraine; *Eg*, early Glacial; *Lg*, late Glacial; *Te*, terrace, numbered as in this paper. Thicknesses of unconsolidated deposits generalized, and not drawn to scale.

represent the later part of the Laramide revolution. Subsequent events are outlined in Figure 16. At some time, probably between the early Eocene and the late Pliocene, there was a period of long continued erosion that reduced the region to the post-mature stage suggested by the accordant summits of the Sawatch Range. It is at least more likely that this erosive stage came early during the time interval mentioned; if an age is to be assigned on the basis of probability it may best be placed in the Oligocene. A later uplift apparently antedated the last pronounced elevation in the Rocky Mountains—that in the late Pliocene—and caused renewed erosion which progressed to a stage of early or middle maturity and left the isolated surfaces, largely as valley flats, now preserved at altitudes approximating 12,000 feet. Then came another uplift probably cor-

responding to the latest pronounced and generally recognized diastrophism in the Rocky Mountains and hence occurring in the late Pliocene. From this there resulted extensive dissection, accompanied or followed by the piling up of the alluvial deposits of Terrace No. 1 on the Arkansas and by the monoclinal shifting of the Eagle River. A subsequent slight uplift caused terracing of the alluvial deposits on the Arkansas and trenching of the monoclinal valley on the Eagle River, and probably initiated the first of the two glacial stages described in this paper.

From this time on the record can be read with greater clarity and has been summarized on page 803.

A POST-DEVONIAN IGNEOUS INTRUSION IN SOUTHEASTERN MISSOURI

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ABSTRACT

A highly altered pipe of femic rock which occurs intrusively in Cambrian sediments and contains inclusions bearing Devonian fossils has been exposed near Farmington, Missouri. The dating of the intrusion as being at least as late as Upper Devonian is significant. Additional possible bearing of the igneous activity in southeast Missouri to the ore deposits of that area is introduced. This intrusive is unique in that it has picked up roughly an equal amount of sedimentary rock materials (carbonate and sand) during its transgression.

The locations of several other nearby post-Cambrian intrusions are given.

The date of the latest igneous activity in southeastern Missouri is a question of much significance in building up the geological history of the state. Besides furnishing a date in the geologic time scale, evidence of post-Cambrian igneous activity in southeastern Missouri has a bearing upon the mineralization of that part of the state, even though it is not necessarily related to it. An igneous rock cutting the Cambrian Lamotte sandstone of this region was discovered by the junior author in August, 1932. The locality is in the southwestern part of Ste. Genevieve County, on State Highway 32, about 6 miles northeast of Farmington, Missouri. The exact location is on the farm of Mrs. Annie E. Williams in the N.W.$\frac{1}{4}$ of the N.E.$\frac{1}{4}$ of Sec. 24, T. 36 N., R. 6 E. The igneous rock was exposed by cutting through the brow of a hill during the construction of the highway in the summer of 1932. The authors visited the intrusive in December, 1932, and studied it in detail in January and May, 1933. During the last visits the approximate outlines of the dike were determined; and, what was very important as a contribution to the geology of the area, positive evidence bearing on the date of the intrusion was discovered.

OTHER OCCURRENCES OF POST-CAMBRIAN IGNEOUS ROCKS IN THIS AREA

Other igneous rocks cutting the Lamotte sandstone and the Bonneterre dolomite (Cambrian) in this vicinity indicate post-

Cambrian igneous activity, but this new evidence reveals an intrusion that was much later, at least Upper Devonian. One of these other occurrences, near Avon, Missouri, has been described by Singewald and Milton.[1] Some miles to the southwest, and nearly on the line between St. Francois and Ste. Genevieve counties (N.E.$\frac{1}{4}$, Sec. 21, T. 35 N., R. 7 E.), is a small outcrop of a dark-green, fine-grained igneous rock. The exposure is small, consisting of two areas about 3 feet across on each side of the road. They cut the Bonneterre dolomite. About 2 miles northwest (S.$\frac{1}{2}$, Sec. 18, T. 35 N., R. 7 E.) of this occurrence there is an outcrop of an igneous rock on the farm of Dr. G. L. Watkins of Farmington, Missouri. This exposure is on the west side of a small creek and only a few feet above the creek bottom. The rock has a bluish-green color and, on the whole, is fine-grained. It contains large (1 centimeter or more across) flakes and books of phlogopite and carbonate areas up to 5 millimeters across. Inclusions of chert and dolomite were found, some inclusions of the latter showing bedding planes and glauconite. It is evident that this dike has included, with and without subsequent reactions, large quantities of carbonates.

About 10 miles west of these two occurrences a diamond-drill hole, put down by the St. Joseph Lead Company, passed through a dark-green, fine-grained dike which was in the Bonneterre dolomite. Numerous veins of calcite and dolomite cut the dike.

Definite rock names have not been assigned to these rocks, because detailed studies of them have not been completed. Such studies will require considerable time, but will make possible, it is hoped, a more complete development of the relationships of the various intrusions and will furnish other valuable contributions to the igneous history of the area.

MODE OF OCCURRENCE OF THE INTRUSIVE

The intrusive is well exposed on the east side of the highway cut, where its course is nearly north and south. The igneous rock is 275 feet wide and has sharp contacts with the Lamotte sandstone on each side. The south contact is nearly vertical, and from this con-

[1] J. T. Singewald, Jr., and Charles Milton, "An Alnöite Pipe, Its Contact Phenomena, and Ore Deposition Near Avon, Missouri," *Jour. Geol.*, Vol. XXXVIII (1930), p. 154.

tact the sandstone dips gently to the south. The north contact is irregular, the igneous rock projecting into the sandstone 3 or 4 feet and stringers from it 2 or 3 feet farther. The intrusive, as seen in the road cut, has come up under a shoulder of the sandstone that projects outward about 20 feet over the igneous rock. The sandstone is much more disturbed on the north end where several faults occur. The dip there is several degrees greater, but could not be determined accurately on account of the disturbed character of the rock. The dip on both ends conforms with that of the general structure. The numerous faults in the sandstone suggest that the intrusive entered the rocks along a fault zone. As faults cut the intrusive, however, all the faulting may have been later. Weller and St. Clair[2] in the report on the geology of Ste. Genevieve County do not mention faulting at this locality.

As the intrusive is deeply weathered, there is no surface evidence as to its shape or size. None of the igneous rock could be found on the west side of the road; hence the road cut must be near the west edge of the intrusive. The sandstone ledge exposed along the north side of the intrusive could be traced southeastward; and, although the southern edge of the sandstone could be followed, no actual exposures of the igneous rock were found. About 500 feet southeast of the road, however, numerous chert pebbles that undoubtedly had been inclusions in the igneous rock were found. These could be followed about 150 feet to the southeast. Their position relative to the sandstone ledge was in keeping with the deduction that they came from the intrusive. The sandstone ledge evidently formed the brow of the hill because of its greater resistance to erosion, this resistance probably being due to the cementation of the sandstone during the intrusion of the igneous rock. The southeastern and southern limits of the intrusive could be located only approximately. It is evident that the intrusive is an elliptical pipe, some 275 feet wide and 600 to 700 feet long. The strike of its major axis is approximately N. 52° W.

It is of interest to note that when the location of this intrusive was called to the attention of State Geologist H. A. Buehler he examined a magnetic profile made by C. O. Reinohl in April, 1932, along the

[2] S. Weller and S. St. Clair, "Geology of Ste. Genevieve County, Mo.," *Mo. Bur. Geol. and Mines*, Vol. XXII (1928), p. 249.

old highway and found that one of the stations showed an exceptional high at the location of the intrusive. The significance of this high is thus now revealed by the presence of the intrusive in the newly made road cut.

MEGASCOPIC DESCRIPTION

The intrusive in the exposure consists of essentially nothing but the weathered rock which has a greenish color shading to yellow and gray. Where completely altered, it is dominantly yellowish. After considerable searching and digging a boulder of the fresh rock with a weathered crust was found.

The fresh igneous rock is dark gray in color. Its texture is unusual for that of an igneous rock. Considering all the constituents, it is fine-grained, yet the rock is made up of dark-gray, rounded aggregates embedded in a lighter gray and slightly more crystalline ground mass. The rock has thus the appearance of a porphyry, or even of a rock with an orbicular texture.

These dark spherules range in diameter from $\frac{1}{2}$ millimeter to a little over 1 centimeter. Their shape, color, and finer grain make them conspicuous features of the rock. They weather to a dark-green color. Many of the spherules contain nuclei of a coarsely crystalline mineral, which by the use of hydrochloric acid and a binocular microscope is generally revealed to be a carbonate. Other minerals, notably mica and magnetite, are present, but they will be described in the petrographic descriptions.

The groundmass of the rock is a lighter gray than the spherules and is more crystalline. Boiling fragments of the fresh rock in hydrochloric acid showed that most of this supposed groundmass is a carbonate and that much quartz is present in rounded grains. The leaching also brought out the shape of the spherules and revealed the presence of much chlorite.

An especially significant feature of the igneous rock is its numerous inclusions (xenoliths) of various other rocks. These xenoliths include blocks of sandstone (now largely quartzite) up to 4 feet across, blocks of chert and sedimentary rocks up to 2 feet in length, as well as granite, gneiss, schist, flint, conglomerate, shale, and dolomite (originally?), and some undeterminable igneous rocks. Great quantities of sandstone (quartzitic), chert, and flint in small sizes occur

in the intrusive. The larger blocks of sandstone which are near the wall are almost horizontal, but the larger fragments of chert and other sediments are essentially vertical. Most of the xenoliths are angular, but some show rounded outlines.

The schist inclusion is a fragment, 3×1 centimeters, of biotite schist.

The fragment of gneiss is $6 \times 4 \times 3$ centimeters. The feldspar in it had altered to clay, but the abundant biotite is unaltered save around the sides of the fragment where it has changed to chlorite. One side of the gneiss fragment shows a slickensided surface.

A striking feature of the chert inclusions is the rigid adhesion of the igneous material to the fragments. The material lying on the surface could be identified by this means as having come from the intrusive; in fact, the southeastern limits of the intrusive were determined by the presence of these chert fragments coated with igneous material. But of the greatest significance were the fossils in these chert fragments, as they made it possible to assign a date to the intrusion.

The conglomerate fragments were identified as conglomerate phases of the Lamotte sandstone, for conglomerates resembling these were found in the lower part of the Lamotte a few hundred yards to the west and stratigraphically lower than those found in the intrusive.

The granite inclusions are coarse-grained and resemble the granite outcropping in Jonca Creek about a mile northeast of the intrusive.

The distribution of the xenoliths within the intrusive has a significance second only to that of the fossils in the chert inclusions. As would be expected, the sandstone xenoliths are confined to the portions of the intrusive nearest its walls. Chert and flint are confined largely to two zones in the south half of the intrusive. Each zone is 20 to 25 feet across, but they are separated by a fine-grained, dark-green igneous rock that is later in age than the chert inclusion zones. Two zones that are relatively free from inclusions of any kind occur on either side of these three zones just described. Near the central part of the northern half of the intrusive there is a narrow zone that contains inclusions unlike those of most other zones. This zone is also cut by numerous small quartz veins, some 2 inches wide, which show vugs.

The presence of these various zones in the intrusive shows that

more than one movement of lava occurred in this channel, and suggests a varied history for the igneous activity of the area. The rock inclusions in certain zones and the fossils in the chert inclusions of other zones definitely indicate the age of those zones. The zones free from inclusions are quite evidently later than the others. The authors expect to present the petrological history in a later paper dealing with the petrology of the intrusion.

The weathered rock, although stained by yellow and red iron oxides, when freshly exposed has a greenish color. This is due primarily to the spherules of igneous material which weather green. The groundmass becomes a light gray which is more or less stained with iron oxides. The weathering was dominantly a leaching of the carbonate, which greatly increased the porosity of the rock and permitted a ready attack of the silicates by the solutions. Clay, chlorite, serpentine, and chalcedony, as well as iron oxides are formed during weathering. The magnetite and chromite(?) are unaltered. Small grains of magnetite are abundant throughout the rock and give portions of the weathered material a darker color. The chlorite preserves its deep-green color in the weathered material. The serpentine has an amorphous, waxy appearance and is usually a dull-clove color.

The chert is only slightly altered, if at all, though the igneous rock adheres to its surface rigidly. The texture of this coating of igneous rock is fully preserved, even on chert inclusions that have been weathered out.

MICROSCOPIC DESCRIPTION

The thin sections used in the description of this intrusive were taken (unless otherwise indicated) from the one unweathered boulder found in the pipe.

A study of them shows the rock to consist of approximately half carbonate, a fifth of rounded quartz grains, and the remainder of serpentine, magnetite, chlorite, epidote(?), phlogopite, a very little clinopyroxene, and a little chromite(?). The original magma was probably peridotitic, but in its transgression through the Lamotte sandstone and higher (younger) formations a maximum amount of these rocks was picked up and mixed within the liquid. The result is an intrusive composed commonly of half sedimentary minerals.

The most abundant primary constituent of the rock was probably olivine. Although none is now present, abundant well-shaped and well-preserved euhedral hexagonal and octagonal "ghosts" occur which are believed to indicate former olivine. They are fairly narrow prisms, 0.2–0.8 millimeters long, terminating in pyramid-like points which may, in turn, be cut by basal pinacoids. The interior of these forms is usually filled with carbonate and fine granular silica which are both presumably alteration products. The carbonate is commonly concentrated in the core and the silica surrounds it, outlining sharply the exterior of the original mineral.

These forms are almost invariably surrounded by a dark, roughly spherical rim, usually as thick or thicker than the core. Other spherules are developed about the quartz grains (Lamotte), and perhaps a third of them contain no included foreign material. These spherules probably represent drops of original magma, whereas the dark rims were formed as magmatic coatings about intratelluric olivine crystals or quartz grains picked up during movement.

The rims and spherules are composed of a very fine-grained, highly altered aggregate which is difficult of accurate mineral determination. Carbonate, however, can be recognized in abundance, and mixed with it is chlorite, serpentine, epidote(?), and fine-grained quartz. The whole is darkened with a dust of iron oxides(?) and small cubes of magnetite.

Small but distinctly lath-shaped forms, now composed of carbonate, occur roughly parallel to the periphery of the spherules. Their shape and the content of carbonate suggest that they were originally plagioclase.

Additional carbonate, in grains of varying size but probably averaging 0.1 millimeter in diameter, fills the space between the dark spherules and the quartz grains and makes up the most abundant mineral group in the rock at present. So impressive was the large amount of carbonate visible in thin sections that a 5-gram chip of the rock, taken at random and presumably representative of the whole, was weighed and leached in hot dilute hydrochloric acid in order to determine roughly the amount of carbonate present. A loss of 62 per cent by weight indicates the amount that was acid soluble. The leached chip is very porous and fragile. Some effervescence in cold

acid and additional action when heated show that both calcite and dolomite are present. Further analytical work to determine the relative amounts of the two is planned in a later study.

It is probable that carbonate from three different sources is present: namely, dolomite caught up mechanically from one of the sedimentary formations; carbonate deposited from the carbonate type of solution in the magma, which was developed by the incorporation of carbonate sediments; and carbonate resulting from the alteration of the olivine.

Rounded quartz grains derived from the Lamotte sandstone make up approximately 20 per cent of the rock. The distribution of the sand is not uniform in quantity throughout the weathered material of the pipe, for some specimens show but little quartz. The sand grains may be surrounded by an igneous rim, as previously described, or may be packed between carbonate grains and igneous spherules. Corrosion of the quartz has taken place to some extent, but is not pronounced.

Small books of a light-brown mica, altered on the edges to a greenish color, are sparsely present in the intrusive. Although none was present in the areas sectioned, several flakes were picked out of the rock and studied in immersion oil mounts. The axial angle is about 10°, optical character is negative, and the refractive index on the basal plane is about $1.580 \pm .005$. The mineral is identified tentatively as phlogopite.

Remnants of two large anhedrons of colorless pyroxene, now strongly altered on the edges and cracks to chlorite, serpentine, and carbonate are shown in one section. Chlorite occurs in small patches and shreds in association with the ferric mineral portions of the rock. Other alteration has resulted in what appears to be an iron-rich serpentine, present in small yellowish-green patches. It is pleochroic, darkening parallel to the elongation, and has moderate birefringence. Elongation is positive. Attempts to isolate the material for index of refraction determination were unsuccessful.

The weathered rock consists of a mixture of limonite-stained clay minerals, quartz sand grains, finely granular quartz, and greenish chlorite and serpentine. Although strongly leached, it still preserves, to a great extent, the original rock structure, the most prominent

feature of which is the pattern of dark spherules set in a lighter-colored matrix.

Because of the loss of much of the carbonate, only a highly porous skeleton of the original rock is left behind. Even the freshest part of the rock available has been altered to such a degree that classification is questionable, and the weathered portion is of practically no value. Because of the presence of the very little pyroxene, the olivine "ghosts," and the dark minerals in the spherules, the belief is held that the original magma was a peridotite.

AGE OF THE INTRUSIVE

As noted above, some of the chert inclusions in the dike were fossiliferous. The fossil material collected was given to Professor E. B. Branson of this University, who very kindly examined it. He was able to identify the following species: *Tropidoleptus carinatus* (Conrad), *Stropheodonta* sp.(?), *Fenestella*(?), *Camarotoechia prolifica* (Hall), *Spirifer* sp.(?), and *Phacops cristata* (Hall).

He states that the material was too fragmentary for absolute identification (it is surprising that this material, having been included in a liquid lava, could still be identified, however unsatisfactorily), but that there can be no doubt but that the fauna is of Devonian age. Apparently, it fits best into the Grand Tower, but might be slightly above or below it. If of Grand Tower age, it is about Middle Devonian.

Some of the chert inclusions, therefore, came out of Devonian beds, and hence the igneous material of the intrusion is at least as young as Devonian. This is the first positive evidence we have of igneous activity in Missouri later than the Cambrian. This discovery thus raises the age of igneous activity in the geological column to the Devonian, and as the evidence from the zones in the intrusive indicates more than one period of movement through the channel it may be still later, as was thought by Weller and St. Clair[3] for the nearby basic intrusives in Ste. Genevieve County. They suggested the Cretaceous age. We know positively that this intrusive is at least Upper Devonian in age.

[3] *Ibid.*, p. 249.

DAEMONHELIX IN THE PLEISTOCENE OF TEXAS

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ABSTRACT

The discovery of structures comparable to *Daemonhelix* in the Pleistocene of Rock Creek, Briscoe County, Texas, extends its range geographically and geologically, and supports the burrow theory of the origin of *Daemonhelix*. Members of the Rock Creek microfauna are reported for the first time: *Cynomys leucurus* (which may have dug the burrows), the first extant species recorded from Rock Creek; *Lepus* sp.; and a tooth apparently indicating an otherwise unknown insectivore. This, the first fossil record of *Cynomys leucurus*, occurs well southeast of its present range. The supposed insectivore, although of problematical affinities, suggests the recent Madagascar Centetidae or the American Oligocene Leptictidae.

The classical Pleistocene locality at the head of Rock Creek, Briscoe County, in the Texas Panhandle, was visited, on June 14 and 15, 1932, by a field party, consisting of Dr. Florence Dowden Wood and the authors. The most interesting discovery consisted of several tubes, which compare strikingly with the enigmatic *Daemonhelix*, or "Devil's Corkscrews," of the Lower Harrison (Lower Miocene) of northwestern Nebraska and adjoining areas, which has been variously interpreted as a plant structure or as a rodent burrow. In addition three small mammals were discovered.

Rock Creek draw, from which the beds were named, heads immediately to the north of Rock Creek filling station, on the McDaniels and Mayfield properties, and drains northward into Tule Creek, which, in turn, flows into the Prairie Dog town fork of the Red River. Rock Creek filling station is 7 miles due west of Silverton, on Texas Highway 86, and 24 miles, by road, east and north of Kress. The specimens described in this paper were found on the property of Mr. Cross McDaniels (for whose courtesies we are much indebted), in the lateral draw containing Gidley's celebrated *Equus scotti* quarry.[1] The structures referred to *Daemonhelix* were found in the south wall of this draw, about half way between the *E. scotti* quarry and the diagonal fence; the mammalian microfauna was found

[1] For map showing location of quarry, see E. L. Troxell, "The Vertebrate Fossils of Rock Creek, Texas," *Amer. Jour. Sci.*, Vol. XXXIX (1915), p. 614, Fig. 1.

along the opposite (northern) rim of the draw. All these specimens occurred at essentially the same level as the *E. scotti* quarry.

Hay[2] recognized twenty-two species of fossil mammals from the Rock Creek locality. Since he failed to include *Preptoceras mayfieldi*,[3] there were actually twenty-three species. As all twenty-three belong to the macrofauna, the discovery of three members of the microfauna is of interest. These consist of: the left ramus of the lower jaw of a prairie dog, *Cynomys leucurus* Merriam (AEW No. 102), bearing the three molars; the left femur of a rabbit (AEW No. 103); and an upper cheek tooth, apparently of a new insectivore (AEW No. 104). The prairie dog is an entirely typical *C. leucurus*,

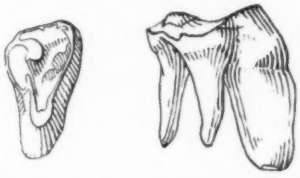

FIG. 1 (left).—Left upper tooth (P^4 ?) of supposed insectivore from Pleistocene of Rock Creek, Texas, crown view, ×4.

FIG. 2 (right).—Tooth shown in Fig. 1, anterior aspect, ×4. (Drawings by F. D. Wood.)

and is the first fossil record of this species, as well as the only known member of the Rock Creek fauna which is still extant. The present range of this species is Wyoming and adjoining parts of Colorado, Utah, and Montana, so that the Rock Creek specimen is about 500 miles southeast of the nearest part of its present range. The supposed insectivore upper tooth (Figs. 1 and 2) is of highly problematic character. It is badly worn, but there is an internal cusp, presumably the protocone, delimiting a transversely elongated central basin. Externally, there was either a single cusp, the parametacone, now separated, by wear of an abnormal type, into two remnants, or else there were originally two incompletely separated external cusps, the paracone and metacone, of which the former was considerably

[2] O. P. Hay, "The Pleistocene of the Middle Region of North America and Its Vertebrated Animals," *Carn. Inst. Wash., Publ. 322A* (1924), p. 239.

[3] Troxell, "A Fossil Ruminant from Rock Creek, Texas, *Preptoceras mayfieldi* sp. nov.," *Amer. Jour. Sci.*, Vol. XL (1915), pp. 479–82.

the larger. There is a well-defined anterior cingulum, a very narrow external cingulum, and a short and faint foreshadowing of a posterior cingulum. There are two slender external roots and a long, massive internal root. The antero-posterior dimension is 2.75 mm. and the transverse diameter is 4.8 mm. The closest comparisons appear with the fourth left upper premolar of various of the recent Madagascar Centetidae, especially *Echinops*, or with the third left upper molar of *Ictops* from the North American Oligocene. It would be unfortunate to base a name, still worse, paleogeographic or phyletic speculation, on such unsatisfactory material; but the tooth definitely suggests either a zalambdodont or a leptictid insectivore.

Two of the *Daemonhelix*-like tubes were well preserved. The more complete (Fig. 3) consisted of a slightly inflected cylinder, about 6 inches in diameter and about 6 feet long, inclined at a low angle with the horizontal, the lower end entering the bank, the higher end (marked by the pick) broken off. Two loose pieces, formerly continuous with the upper end, have broken off and appear below the section in place (Fig. 3), adding about 3 more feet of length to this specimen. The upper portion of the second specimen is horizontal. Any parts that may formerly have extended higher than the present left end (marked by the pick, Fig. 4) have disappeared. At the right end of this horizontal portion, the tube bends downward, forming, with the horizontal section, an acute angle. After a few feet, this portion curves away from the observer. This curved part cannot be distinguished in the photograph, as it has almost disintegrated. After this nearly obliterated region, the cylinder bends toward the observer and downward, straightens out, and disappears into the ground. The upper surface of the horizontal section has weathered away, exposing the less firmly indurated interior of the cylinder. This interior part of the cylinder consists of sand resembling the matrix, but is definitely more consolidated. In general appearance, these cylinders compare strikingly with *Daemonhelix* from the Lower Harrison of Nebraska (Fig. 5).[4] The diameters are within the range

[4] Compare, also, figures published elsewhere, e.g., E. H. Barbour, "Additional Notes on the New Fossil, *Daimonelix*," *Nebr. Univ. Stud.*, Vol. II (1894), Pl. XII; "History of the Discovery and Report of Progress in the Study of *Daemonelix*," *Nebr. Univ. Stud.*, Vol. II (1897), Pl. V; "Nature, Structure and Phylogeny of *Daemonelix*," *Bull. Geol. Soc. Amer.*, Vol. VIII (1897), Pl. XXIV; O. Abel, *Amerikafahrt* (Jena: Gustav Fischer, 1926), Fig. 248.

of the typical Harrison forms. The Texas specimens differ in the absence, so far as observed, of the definite spiral so characteristic of

FIG. 3.—*Daemonhelix*-like structure from Pleistocene of Rock Creek, Texas

FIG. 4.—*Daemonhelix*-like structure from Pleistocene of Rock Creek, Texas

the Nebraska *Daemonhelix*. The first specimen resembles the "rhizome," only, of the Nebraska form. The second specimen, if comparable to the spiral, is certainly much less regular; in this difference

from the Nebraska form it closely approaches Peterson's casts of prairie dog burrows.[5] In view of this resemblance, the discovery of a fossil prairie dog, close at hand, permits a plausible inference as to the possible identity of the excavator. On account of the conditions under which we were allowed to work, neither of these tubes was collected, in whole or in part. Hence no comparison can be made between the microscopic structure of the Texas and Nebraska forms.

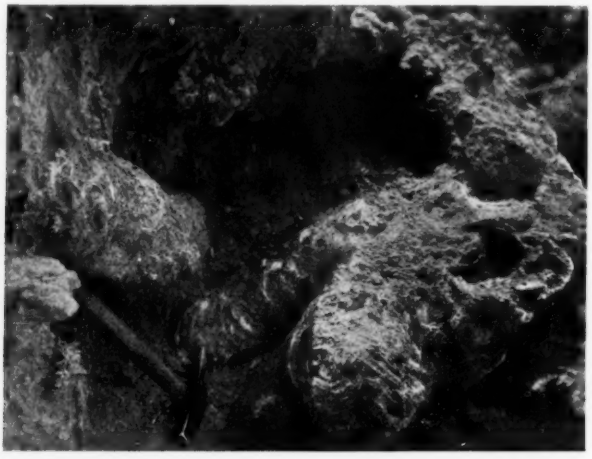

FIG. 5.—*Daemonhelix* from Lower Miocene, Agate, Sioux County, Nebraska

Before further discussion of the significance of the Rock Creek material, it seems desirable to summarize the known data and present status of opinion concerning *Daemonhelix*[6] in its typical occur-

[5] O. A. Peterson, "Description of New Rodents and Discussion of the Origin of *Daemonelix*," *Mem. Carn. Mus.*, Vol. II (1906), pp. 185–91, Figs. 9–10.

[6] Barbour successively introduced the forms *Daimonelix* and *Daemonelix*. Kenyon (F. C. Kenyon, "In the Region of the New Fossil, *Daemonelix*," *Amer. Nat.*, Vol. XIX [1895], pp. 213–27, Pl. I) used *Daemonelix*, and Lydekker (R. Lydekker, "Fossil Marmot Burrows," *Knowledge and Illustrated Scientific News* [n.s.], Vol. II [1905], p. 134) used *Daemonohelix*. The form *Daemonhelix*, introduced by von Ammon (L. von Ammon, "Ueber das Vorkommen von 'Steinschrauben' (*Daemonhelix*) in der oligocänen Molasse Oberbayers," *Geognostische Jahreshefte* [1900], 13 Jahrgang, pp. 55–69, Figs. 4, 5, Pl. I.), is an emendation apparently warranted by the *International Rules of Zoölogical Nomenclature* (Art. 19, "Appendix and Opinions 34 and 36"), if *Daemonhelix* is to be treated as a taxonomic subject.

rence. The published factual data are nearly all due to Barbour[7] and Peterson.[8] *Daemonhelix* is found, in large numbers, only in the Lower Harrison of Sioux County, in northwestern Nebraska; but, according to Barbour,[9] it is occasionally found in beds of equivalent age in southwestern South Dakota, eastern Wyoming and Colorado, and as far south as Benkleman, Nebraska, near the Kansas line. The typical gross structure consists of a vertical, open spiral, either dextral or sinistral, which, at or near the base, connects with a rising, relatively straight, lateral cylinder (the "rhizome"), with one or more enlargements. The usual diameters vary from 6 inches to a foot. The *Daemonhelix* spiral occasionally surrounds a central cylinder, the axis, which has never been adequately explained, although various interpretations have been offered or are conceivable. Thin sections, made in any part of the structure, show characteristic root tissue and rootlets of varying sizes, nearly all identifiable as angiosperms.[10] About two dozen specimens of *Steneofiber*, a castorid rodent, have been found inside *Daemonhelix*, including several skeletons, essentially complete, with the bones in natural position. However, opposing, to some extent, the presumption that *Steneofiber* constructed these tubes as burrows, two skeletons, one of a large mammal,[11] the other of *Oxydactylus*,[12] were found involved with (or pierced by?) *Daemonhelix*. Riggs also found two genera of carnivores and a *Merychyus*

[7] "Notice of New Gigantic Fossils," *Sci.*, Vol. XIX (1892), pp. 99–100, 3 figs.; "Notes on a New Order of Gigantic Fossils," *Nebr. Univ. Stud.*, Vol. I (1892), pp. 301–35, 18 figs., Pls. I–VI (Abstr., *Jour. Geol.*, Vol. I, p. 421); "Additional Notes on the New Fossil, *Daimonelix*," *op. cit.*; "Is Daemonelix a Burrow? A Reply to Dr. Theodor Fuchs," *Amer. Nat.*, Vol. XIX (1895), pp. 517–27, 3 figs., 1 pl.; "History of the Discovery and Report of Progress in the Study of *Daemonelix*," *op. cit.* (Abstr., *Nebr. Acad. Sci.*, Pub. 5 [1896], pp. 24–28); "Nature, Structure and Phylogeny of *Daemonelix*," *op. cit.*; "Present Knowledge of the Distribution of *Daimonelix*," *Sci.* (n.s.), Vol. XVIII (1903), pp. 504–5.

[8] "Recent Observations upon *Daemonelix*," *Sci.* (n.s.), Vol. XX (1904), pp. 344–45; "Description of New Rodents and Discussion of the Origin of *Daemonelix*," *op. cit.*

[9] "Present Knowledge of the Distribution of *Daimonelix*," *op. cit.*

[10] O. E. Jennings, Appendix to Peterson, "Description of New Rodents and Discussion of the Origin of *Daemonelix*," *op. cit.*

[11] Barbour, "Additional Notes on the New Fossil, *Daimonelix*," *op. cit.*, Pl. IV.

[12] E. S. Riggs, "Loup Fork Beds of Eastern Wyoming" (Abstr.), *Sci.* (n.s.), Vol. XXIX (1909), p. 196.

jaw inside the spirals, which might mean simply that they had fallen, been carried, or been washed down the holes.

Barbour[13] constructed a supposed phylogeny of *Daemonhelix*, referring numerous structures besides the typical one to this form. His *Daemonhelix* fibers or tubules are quite certainly small roots, whether found free, or etching rhinoceros or other bones; and this is presumably to what he refers when he speaks of a mastodon tusk etched by rootlets of *Daimonelix*.[14] Kindle[15] apparently regarded some of the forms as concretionary, and this seems a plausible explanation for, at least, the "cakes" and "balls." Barbour's proposed phylogeny has never secured general acceptance.

Comparisons have been made with various much smaller spiral structures: with *Taonurus* (=*Spirophyton*) and *Spiraxis* of the marine Paleozoic of New York and Pennsylvania;[16] with *Xenohelix* (?) *mexicana* from the marine Cretaceous (?) of Coahuila, Mexico, and *Xenohelix* (?) *clarki* from the marine Miocene of California;[17] with "Steinspiralen," "Steinschrauben," or "screw-stones" of the marine Miocene of Switzerland and Austria;[18] with *Xenohelix marylandica* from the marine Miocene of Maryland;[19] and with *Daemonhelix*

[13] "History of the Discovery and Report of Progress in the Study of *Daemonelix*," *op. cit.*; "Nature, Structure and Phylogeny of *Daemonelix*," *op. cit.*

[14] Barbour, "The Boyd County Mastodon, *Tetrabelodon osborni*," *Nebr. Geol. Surv.*, Vol. IV (1917), p. 504.

[15] E. M. Kindle, "Range and Distribution of Certain Types of Canadian Pleistocene Concretions," *Bull. Geol. Soc. Amer.*, Vol. XXXIV (1923), pp. 611, 631.

[16] J. F. James, "Remarks on *Daimonelix* or 'Devil's Corkscrew' and Allied Fossils," *Amer. Geol.*, Vol. XV (1895), pp. 337–42, 1 fig., 2 pls. See also: J. Hall, "Observations upon Some Spiral-Growing Fucoidal Remains of the Paleozoic Rocks of New York," *N.Y. State Cab. Nat. Hist., Ann. Rept. Regents Univ.*, Vol. XVI (1863), pp. 76–83, Figs. 1–4, Pl. II.; J. S. Newberry, "Descriptions of Some Peculiar Screw-Like Fossils from the Chemung Rocks," *Ann. N.Y. Acad. Sci.*, Vol. III (1885), pp. 217–20; "Some Peculiar Screw-Like Casts from the Sandstones of the Chemung Group of New York and Pennsylvania," *Trans. N.Y. Acad. Sci.*, Vol. III (1885), pp. 33–34.

[17] W. C. Mansfield, "Some Peculiar Fossil Forms from California and Mexico," *Proc. U.S. Nat. Mus.*, Vol. LXXVII (1930), pp. 1–3, Pl. I–II.

[18] Abel, *op. cit.*, p. 385; O. Heer, *The Primeval World of Switzerland* (trans. J. Heywood), (London: Longmans, Green and Co., 1876), 2 vols., Vol. II, pp. 102–3, 1 fig.; James, *op. cit.*

[19] Mansfield, "Some Peculiar Fossil Forms from Maryland," *Proc. U.S. Nat. Mus.*, Vol. LXXI (1927), pp. 1–9, Pls. I–V. (Contains some minor citations of *Daemonhelix* literature not included in this paper.)

Krameri von Ammon,[20] from the Cyrena Beds of the Oligocene (Aquitanian) fresh (brackish?) water Molasse of Peissenberg, in Southern Bavaria. It is, however, strongly improbable that large spiral structures in the fluvio-eolian Lower Miocene of Nebraska should have a genesis the same as, or even similar to, small spirals, one-sixth the diameter or less, from marine rocks of about the same age in California, Maryland, and Europe, to say nothing of the Mexican Cretaceous or the New York Paleozoic. The Peissenberg occurrence is less obviously irrelevant; but as the Cyrena beds were deposited in a lake or lagoon, they are more likely to be interpreted in terms of the marine than of the eolian occurrences. One is tempted to interpret all the post-Paleozoic aquatic occurrences as casts of the borings of marine, and fresh or brackish water, mollusks, respectively; but, whatever light they may throw on each other, they can have little relation to occurrences in eolian formations.

After long discussion, the hypotheses regarding the origin of *Daemonhelix* have been reduced to two: the root hypothesis, held by Abel, Barbour, Kenyon, and Wortman;[21] and the rodent-burrow hypothesis, supported by Abel, Cope, Fuchs, Grabau, Matthew, Ortmann, Peterson, and Woodward.[22] Peterson[23] gives the evidence for the latter. A non-committal position was assumed by Barbour,

[20] Von Ammon, *op. cit.*

[21] Held, in various forms, by: Kenyon, *op. cit.;* J. L. Wortman, "On the So-Called Devil's Corkscrews of Nebraska," *Amer. Nat.*, Vol. XIX (1895), p. 403; Barbour, "Nature, Structure and Phylogeny of *Daemonelix*," *op. cit.;* Abel, *op. cit.*, pp. 288, 354, 357, 358, 382–94, 9 figs.; and Abel, "Das *Daemonelix-Problem*," *Palaeont. Zeit.*, Vol. IX (1927), pp. 179–80.

[22] Held by: E. D. Cope, "A Supposed New Order of Gigantic Fossils from Nebraska," *Amer. Nat.*, Vol. XXVII (1893), pp. 55–60; T. Fuchs, "Ueber die Natur von *Daimonelix*, Barbour." *Ann. K. K. Naturhist. Hofmus.*, Wien, VIII (1893), Notizen, pp. 91–94; Peterson, "Recent Observations upon *Daemonelix*," *op. cit.;* "Description of New Rodents and Discussion of the Origin of *Daemonelix*," *op. cit.;* A. E. Ortmann, "Teufels-Korkzieher," *Aus der Natur*, Leipzig (1909), Jahrgang 5, H. 6, pp. 177–80, 3 figs.; W. D. Matthew, *Zoölogy. Science-History of the Universe*, Vol. VI (1909) (New York: Current Literature Publishing Co.), p. 160; "Symposium on Ten Years' Progress in Vertebrate Paleontology," *Bull. Geol. Soc. Amer.*, Vol. XXIII (1912), p. 186; Abel, Grundzüge der Palaeobiologie der Wirbeltiere" (Stuttgart: Schweizbart, 1912), pp. 84–86, 1 fig.; A. W. Grabau, *A Textbook of Geology*, Vol. II, *Historical Geology* (Boston: D. C. Heath and Co., 1921), pp. 43–44; and K. von Zittel, *Text-Book of Palaeontology*, Vol. III, *Mammalia* (ed. A. S. Woodward) (London: MacMillan, 1925), p. 106.

[23] "Description of New Rodents and Discussion of the Origin of *Daemonelix*," *op. cit.*

O'Harra, Osborn, and Riggs.[24] Other proposed explanations, such as the sponge and aquatic alga hypotheses,[25] have now been abandoned. The two alternative hypotheses, in their modern forms, contrast considerably less than formerly, as they vary from (1) a root, frequently hollowed or removed by decay, with the cavity thereafter open to occupation as a burrow;[26] through (2) "a plant growth which seems to have followed the course of burrows";[27] to (3) a burrow followed by rootlets,[28] giving a mesh of roots, such as may clog a drainpipe.[29] Barbour, the principal worker on *Daemonhelix*, formerly regarded the burrow hypothesis as untenable, largely because the Harrison was then believed to be lacustrine.[30] The later overthrow of the "lake-bed" hypothesis destroyed the force of this apparently convincing argument. Barbour also argued that burrows made in the loose sand of the Harrison formation would collapse. The presence of large quantities of volcanic dust[31] may help to explain the coherence of the material, taken in conjunction with Peterson's suggestion[32] of the cementing effect of the secretions of the

[24] Barbour, "Additional Notes on the New Fossil, *Daimonelix*" *op. cit.;* H. F. Osborn, "A Paleontological Trip to Northwestern Nebraska," *Sci.* (n.s.), Vol. XXVI (1907), pp. 871–72; "Cenozoic Mammal Horizons of Western North America," *U.S. Geol. Surv. Bull. 361* (1909), p. 73; *Age of Mammals* (New York: Macmillan, 1910), pp. 234–35; Riggs, *op. cit.*, C. C. O'Harra, "The Badland Formations of the Black Hills Region," *S. Dak. State School of Mines, Bull. 9* (1910), pp. 51–53; "The White River Badlands," *ibid., Bull. 13* (1920), pp. 59–61 (revised and enlarged edition of *Bull. 9*).

[25] Barbour, "Notice of New Gigantic Fossils," *op. cit.*, and "Notes on a New Order of Gigantic Fossils," *op. cit.;* H. F. Cleland, *Geology, Physical and Historical* (New York: American Book Co., 1916), pp. 631–32.

[26] Riggs, *op. cit.;* Barbour, verbal opinion, cited by Abel, *Amerikafahrt*, *op. cit.*, p. 288, and "Das *Daemonelix*-Problem," *op. cit.*

[27] Barbour, "A Preliminary Report on the Nebraska State Museum," *Nebr. State Mus. Bull. I*, 1 (1924), p. 14.

[28] Barbour, "Is *Daemonelix* a Burrow? A Reply to Dr. Theodor Fuchs," *op. cit.*, suggested, but discarded; Peterson, "Description of New Rodents and Discussion of the Origin of *Daemonelix*," *op. cit.*

[29] Jennings, Appendix to Peterson, *op. cit.*

[30] Barbour, "Additional Notes on the New Fossil, *Daimonelix*," *op. cit.;* "Is *Daemonelix* a Burrow? A Reply to Dr. Theodor Fuchs," *op. cit.;* "History of the Discovery and Report of Progress in the Study of *Daemonelix*," *op. cit.;* and "Nature, Structure and Phylogeny of *Daemonelix*," *op. cit.*

[31] A. D. Howard, "The Lithology of Selected Fossiliferous Tertiary Sediments," *Amer. Mus. Novitates, No. 544* (1932), pp. 9–11.

[32] "Description of New Rodents and Discussion of the Origin of *Daemonelix*," *op. cit.*

rodents. At the present time, it is fairly certain that the burrow hypothesis is the more widely accepted one.

If, as the authors believe, the Rock Creek structures may legitimately be designated as *Daemonhelix* (Figs. 3–5), this discovery not only extends the geographic range from Nebraska to the Texas Panhandle and the geologic range from the Lower Miocene to the Pleistocene, but also strongly supports the burrow hypothesis for the origin of *Daemonhelix*. As stated above, the Rock Creek structures are similar to the typical *Daemonhelix*, and are even more suggestive of Peterson's casts of recent prairie-dog burrows. The presence of *Cynomys leucurus* supplies a plausible agent. Finally, whatever one may be able safely to suppose about the flora of the Nebraska Lower Miocene, it is highly improbable that, during the Pleistocene, the sandy soil of Rock Creek, Texas, supported an unknown plant, unrepresented in the modern flora, and sufficiently large to have had a root or other structure of this size (Figs. 3–4). Abel's deductions from the assumed validity of the root hypothesis as to the desert climate of the Harrison[33] might be difficult to disprove positively, however little they accord with the known fauna; but it would be hardly plausible to expect, for Rock Creek, fundamentally different environmental conditions from those of the present day, except for the probability of a somewhat lower temperature and somewhat greater rainfall, during the glacial stages, neither of which would tend toward producing a desert environment. In this connection, it is interesting to note that Rock Creek is at present in the Upper Austral zone, and that *Cynomys leucurus* now inhabits the Transition zone, suggesting that, during the deposition of the Rock Creek beds, the climate of the Texas Panhandle was cooler than at present. However, the Rock Creek fauna (including horses, camels, peccaries, elephants, ground sloths, dogs, rabbits, prairie dogs, insectivores(?), and tortoises) would seem to indicate an environment not totally different from the present plains condition in the same region. If the Rock Creek form referred to *Daemonhelix* is admitted to be the filling of the burrow of a Pleistocene rodent, the burrow hypothesis for the similar Nebraska structures is strongly reinforced.

[33] Abel, *Amerikafahrt*, *op. cit.*

THE PERMIAN-TRIASSIC PROBLEM IN WESTERN OKLAHOMA

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In an article in this *Journal*[1] entitled "Evidence Indicating the Limits of the Triassic in Oklahoma, Kansas, and Texas," Robert Roth places the Permian-Triassic contact at the base of the Whitehorse sandstone. He thus includes with the Triassic the Whitehorse sandstone, the Cloud Chief gypsum, and the Quartermaster. For these three units he proposes a new name, the "Custer."

The evidence presented by Roth, as supporting this correlation, may be briefly summarized as follows:

1. An unconformity of some magnitude exists at the base of the Whitehorse.

2. The Channel sandstones, in widely separated areas, are correlated and placed at the base of the Whitehorse.

3. The conditions of deposition of the Whitehorse and overlying Permian were different from the conditions of deposition of the sediments below the Whitehorse.

4. The ilmenite-leucoxene ratio indicates that the Whitehorse is considerably younger than the underlying sediments.

5. The lithology of the Whitehorse sandstone and the overlying Permian sediments is different from that of the underlying sediments, but similar to that of the Lower Triassic in the Black Hills and central Arizona.

6. The fauna of the Verden Channel sandstone may be Triassic.

In this article each of the preceding points will be considered in order. In discussing (1) the unconformity at the base of the Whitehorse, Roth states,[2]

> At the southeast end of the Anadarko Basin, that is, in Grady, Stephens, and Comanche counties, it is strongly suggested that the Dog Creek and Blaine formations are . . . . non-existent due to overlap. Further evidence of this overlap

[1] Vol. XL (1932), pp. 688–726. [2] *Ibid.*, p. 713.

is shown by the dolomites at the base of the Blaine which continue much farther south after the Blaine gypsum is cut out. The Marlow looks exactly like the Flower-Pot which underlies the Blaine.

It should be noted that the Marlow is the lower part of the Whitehorse, the upper member being known as the Rush Springs.

The presence in Grady County of an unconformity of such magnitude that both the Dog Creek and the Blaine formations have been removed by erosion is not supported by the field evidence, according to Becker.[3] Unfortunately, Becker's paper is not mentioned by Roth. Becker's sections[4] clearly show that the apparent absence of the Blaine outcrop in Grady County is due to lateral gradation of the Blaine into shale and sandstone. Furthermore, this interpretation is supported by the subsurface evidence as there is no difficulty in tracing the Blaine as far to the southeast as the Chickasha gas field (T. 5 N., R. 8 W.) where the Blaine horizon is found in nearly all wells at a depth of 400–500 feet. This is about 40 miles south of the locality where the Blaine dolomite disappears and within 15 miles of the southeast end of the Anadarko basin. The Dog Creek shale has been traced into the Anadarko basin by core drills. It gradually increases in thickness toward the southeast to more than 300 feet. The outcrops of the Dog Creek have been masked by weathered sand from the superjacent Whitehorse which makes its tracing uncertain on the surface. Because of the difficulties in tracing the Blaine and Dog Creek outcrop in the southeast end of the Anadarko basin, Becker proposed the name "El Reno" for the sediments from the base of the Duncan to the base of the Marlow. Becker has also shown that this interval has approximately the same thickness (about 600 feet) as the combined thickness of the Flower-Pot, Blaine, and Dog Creek on both sides of the Anadarko basin. Thus, the El Reno represents a more sandy phase of deposition in this area during Flower-Pot, Blaine, and Dog Creek time. This type of lateral gradation of sediments is a characteristic condition of Red Bed deposition in Oklahoma and Kansas throughout the Permian.

Again, Roth writes,[5] "Near Wildcat Mounds in Woods County,

[3] C. M. Becker, "Structure and Stratigraphy of Southwestern Oklahoma," *Bull. Amer. Assoc. Petr. Geol.*, Vol. XIV (1930), pp. 37–56.

[4] *Ibid.*, pp. 52–53.

[5] *Op. cit.*, p. 713.

the complete removal of Dog Creek and Blaine formations prior to Custer deposition may be observed." While this leaves the locality of the unconformity indefinite, the writer and others have been able to trace the Blaine and Dog Creek continuously through this locality, and they find that both formations maintain their normal thickness throughout this area. The region is one of comparative high relief, and blocks of Whitehorse sandstone have slumped down, partly because of undermining and removal of the underlying soft shales and partly on account of solution of the gypsum in the Blaine, which may explain why Roth failed to observe the Blaine and the Dog Creek. Nevertheless, back of the slumped Whitehorse is found the normal sequence of these formations.

And again, in Kansas, Sec. 18, T. 30 S., R. 15 W., Roth reports[6] an angular contact between the Dog Creek and the Whitehorse. Although he does not regard this of much importance, it should be noted that in this area the Dog Creek is less than 40 feet in thickness. With this thickness and with a dip of only 1° the formation would be entirely removed, up dip, in less than $\frac{1}{2}$ mile. The formation, however, continues throughout the area maintaining its normal thickness. The angular contact, therefore, seems more likely due to cross bedding which is of frequent occurrence in the Oklahoma Red Beds.

(2) Roth places the Channel sandstones at the base of his Custer[7] (Marlow base) wherever they are found in Oklahoma and Texas. His reason is that ". . . . the material below these channel deposits does not carry Custer lithology." Channel sandstones, however, have been reported in Texas 225 feet above the base of the Whitehorse. They are found 80 feet above the base of the Whitehorse at Verden, Oklahoma; 65 feet above the base in Sec. 33, T. 12 N., R. 9 W., Oklahoma, in the bluffs on the north side of the South Canadian River; 50 to 100 feet above the base in several localities in Woods County, Oklahoma; and east of Woodward, Oklahoma, the Channel sandstones are found 140 feet above the base. While the Channel sandstones thus occur at many horizons within the Whitehorse, no locality has been reported where they occur at the Whitehorse base (Marlow base).

(3) Roth gives the impression[8] that only the Permian, below the

[6] *Ibid.* [7] *Ibid.*, p. 709. [8] *Ibid.*, p. 723.

Whitehorse, shows an increase in the coarseness of the clastic sediments as they approach the Anadarko basin. He states, "The beds above the Verden channel sandstone, however, do not change laterally into this basin." Nevertheless, in northwest Oklahoma the Whitehorse is interstratified with shale and considerable gypsum which can be traced by outcrop to a point 4 miles southwest of Thomas, Oklahoma.

Southeast of Thomas, in the Anadarko basin, the Whitehorse is essentially sandstone. Evidently the Whitehorse offers no exception to the increasing coarseness of clastic sediments in the southeast end of the Anadarko basin. Moreover, not all the sediments below the Whitehorse increase in coarseness as they approach the southeast end of the Anadarko basin, for it is well known that the Cedar Hills and Harper sandstones of Kansas and northern Oklahoma grade laterally into Hennessey shale to the southeast. Furthermore, it should be noted that products of evaporation such as dolomite, anhydrite, and even salt are found in the Permian of Oklahoma from Wellington to Cloud Chief time. It does not follow that these would occur at the same place, for the basin in which the evaporites were deposited is known to have shifted progressively southwest from Wellington to Quartermaster time, and it must have been surrounded on all sides by clastic sediments.

(4) By means of the ilmenite-leucoxene ratio, Roth attempts to establish the relative ages of geologic formations. He states[9] that wherever leucoxene is high, relative to ilmenite, the rock is older. He also says[10] "In looking at the table it can readily be seen, starting with the Wellington, that the ratio of ilmenite to leucoxene is 1–4; Garber, 1–5; Hennessey, 1–14; Duncan, 1–17; and Whitehorse, 1–2." In four cases (Wellington, Garber, Hennessey, and Duncan) this ratio is the reverse of that which Roth maintains is proof of age relations; in only one case cited by him (Duncan to Whitehorse) does it support his contention. It is obviously not reliable to determine the age of rocks by the rate of alteration of ilmenite to leucoxene. Other factors difficult to evaluate enter into this ratio, such as the amount and condition of the ilmenite and leucoxene at the time of

[9] *Ibid.*, p. 722.

[10] *Ibid.*

deposition, the rate and facility for alteration after deposition, and the length of time the sediments have been exposed to weathering. Furthermore, it is not known that all leucoxene is derived from ilmenite nor that leucoxene is the only alteration product of ilmenite.

(5) Correlation by lithology from well cuttings taken at long distances and without surface outcrops is not reliable, and important conclusions cannot safely be drawn from such data. Yet it is largely upon such evidence that Roth correlates the Upper Permian of Oklahoma with the Triassic as far northwest as the Black Hills. Among the Red Beds it would indeed be a remarkable formation which is characterized by lithologic similarity over such great distances. This is well illustrated by the Whitehorse itself, which, in stratigraphy and texture is very different in northwest Oklahoma, on the Kansas-Oklahoma line, from that of the Whitehorse along the axis of the Anadarko basin.

(6) Only in the Channel sandstones of the Whitehorse have fossils been found. While Roth points out that some of the species occur also in the Triassic, no other paleontologist who has studied them has ever questioned their Permian affinities. Unfortunately, these fossils are poorly preserved and identification of the species is, therefore, open to some uncertainty.

In addition to the evidence presented by Roth, one should not fail to take into consideration the time interval necessary for the organic development of the vertebrates. The organic development of the vertebrate fauna indicates a great time interval from the highest horizon of Permian vertebrates (in the Clear Fork of Texas and the Hennessey of Oklahoma) to the lowest occurrence of these in the Upper Triassic of Texas (the Dockum). According to J. Willis Stovall,[11] the vertebrate fauna of the Permian is characterized by the dominance of amphibia as compared with reptiles, whereas the Dockum fauna is characterized by a diminution in numbers of amphibia and the appearance of many newly evolved types of reptiles which become the dominant element of the Dockum fauna.

What depositional units and erosional periods represent this great time interval in Oklahoma? The depositional units for the Oklahoma area are the Flower-Pot, Blaine, Dog Creek, Whitehorse,

[11] Oral communication.

Cloud Chief, and Quartermaster. These represent a thickness of some 1,500 feet of which approximately 100 feet consists of evaporites and 1,400 feet of clastic sediments, perhaps $\frac{2}{3}$ sandstone and $\frac{3}{5}$ shale. The time interval represented by unconformities within the Permian could scarcely have been very great. Only two noteworthy unconformities are present: the Whitehorse–Cloud Chief unconformity and the Cloud Chief–Quartermaster unconformity. Not all field men will agree upon the presence of the Whitehorse–Cloud Chief unconformity, though we feel that it is quite well established. Although it is difficult to determine the duration of the erosional interval between the Cloud Chief and the Quartermaster, it does not appear to have been very great.

Hence, the time necessary for the evolution of the vertebrates must be represented by erosion subsequent to Quartermaster deposition and prior to the deposition of the Dockum. This erosional period constitutes a major unconformity, and it would seem altogether appropriate that this unconformity should mark the end of the Paleozoic and the beginning of the Mesozoic in this area.

While not important in this discussion, Roth suggests a unique cause for frosted surfaces on sand grains. He states[12] that

> Under high magnification, the St. Peter grains show that the frosting really is due to a secondary enlargement by percolating waters containing dissolved silica. This secondary enlargement is in the form of minute crystal facets starting to form a complete crystal of quartz out of the individual sand grain. It is in no sense a drusy character involving individual crystals, but in reality one crystal developing a great number of facets upon its face.

In the absence of proof supporting this statement, it seems improbable that reflected light from the crystal facets could produce the appearance of frosting on sand grains.

[12] *Ibid.*, p. 718.

REVIEWS

Ergebnisse Geologischer Forschungen in Minas Geraes (Brazilien). By B. von Freyberg. Stuttgart: E. Schweizerbart'sche Verlagsbuchhandlung, 1932. Pp. 403; figs. 53; pls. 27; colored maps 2. M. 52.

From shortly after 1727 till their discovery in South Africa in 1869, Minas Geraes was the world's chief producer of diamonds. During these years gold was also an important product and to a lesser extent the state of Minas was famous for its topaz, tourmalines, and certain other minerals, and thus justified its name. In the future its greatest mineral resource, iron ore, is likely to bring it again to the fore. Though prospected and settled for a couple of centuries its general geology has been in need of more systematic study.

In this volume by von Freyberg is summarized the information obtainable from many scattered sources together with the results of the author's own studies during four visits to this portion of Brazil. The result is a good systematic treatment of the general geology of the state of Minas Geraes.

The stratigraphic column is not an elaborate one. An old complex of schists, gneisses, and granites underlies large areas, mostly lowland with dense forests. Above this are two systems, designated the Minas series and Itacolumy series, of moderately folded and faulted quartzites and schists, the former of which contains astonishingly rich and extensive deposits of hematite. These two systems are thought to be of Proterozoic age, though an early Paleozoic age is not precluded. They form the Serra do Espinhaço or Backbone Range of Brazil. Inland from this mountain range, in the drainage basin of the Rio São Francisco, occurs the less deformed Bambuhy series assigned with some question to the Silurian or Devonian. This series is followed by the flat-lying Gondwana series of Triassic red sandstones and shales with basaltic lavas, and these in turn by local occurrences of Cretaceous and Tertiary beds of relatively less importance.

R. T. C.

Kenora Sheet, Map 266 A, 1933, Geological Survey of Canada. Compiled by T. L. TANTON from surveys of the Geological Survey and the Ontario Bureau of Mines. Scale: 1 inch to 8 miles.

This colored geologic map shows a large area, appreciably larger than the state of Illinois, which lies in Ontario, north of the state of Minnesota and east of the province of Manitoba.

The geologic succession given in the legend is: (1) Couchiching paragneiss and sediments, (2) Keewatin volcanic complex, (3) Laurentian batholithic intrusives, (4) Temiskamian sediments (including Seine, Steeprock, Windigokan, Abram, and other series, (5) Algoman batholithic intrusives, (6) Gunflint formation, (7) Rove formation, and (8) Keweenawan diabase sills. The Gunflint and Rove formations make up the Animikie. These beds have a relatively low angle of dip, contrasting strongly to the volcanics (2) and the sediments of earlier age (1) and (4) which are strongly deformed.

A brief explanation of the geology and economic resources of the area is printed on the margin of the map sheet.

Of special interest are the extensive areas of sediments designated Couchiching, indicating Tanton's belief in the existence and importance of this series; the restriction of the Laurentian to three very small areas, much less than 1 per cent of the total granite area; and errors in mapping in the Sioux Lookout region due to lack of information. It would be interesting to know on what basis some correlations were made, particularly the designation of the paragneisses of the lower English River area as Temiskamian and the sediments of Eagle Lake, Dryden, and Sandybeach Lake as Couchiching. The latter sediments, incidentally, should be extended 25 miles farther northeast to at least the east end of Lake Minnitaki.

The Geological Survey is to be commended for the publication of this map. The great advances in mapping of this region in the past decade and the increasing importance of its gold deposits, as well as the fact that it includes the classic areas of Lake of the Woods and Rainy Lake mapped by Lawson in the eighties, make the map especially valuable. The map is well executed and together with Map 155 A (Lake Huron Sheet) (1929) is indispensable for students of pre-Cambrian geology.

F. J. PETTIJOHN

Minerals Yearbook, 1932–33. Washington: U.S. Bureau of Mines, 1933. Pp. 819; figs. 90. $1.25.

For over fifty years official statistics of the mineral industries of the United States have been issued in the annual volume of *Mineral Re-*

sources, first by the U.S. Geological Survey and since 1925 by the U.S. Bureau of Mines. Of late years these have appeared in two volumes, one on metals and one on non-metals. Now these data appear in a new and more compact form in a single blue-covered volume entitled *Minerals Yearbook*—which will be issued more promptly than formerly after the close of the year to which the figures relate. The first volume presents the statistics for two years, 1931 and 1932, but subsequent volumes will be issued annually. The convenient availability of the statistical data in a single volume is a welcome innovation.

E. S. B.

Invertebrate Zoology. By ROBERT W. HEGNER. New York City: Macmillan Co., 1933. Pp. 570; figs. 403; pls. VIII. $3.75.

This useful text is a fairly complete revision of Hegner's *Introduction to Zoology* published in 1912. The older volume was limited in scope, since it discussed in considerable detail only a few of the invertebrate animals. The present text has been expanded to include descriptions of all groups of invertebrates. Furthermore, the book is distinctly up to date in that the results of pertinent recent investigations are included.

Students of invertebrate paleontology, who all too commonly are poorly grounded in zoology, will find this text a handy reference work. They will have to remember, however, that zoologists are not likely to be much better in paleontology than paleontologists are in zoology. With this in mind they should not be too surprised to learn, among other things, that the "*Lingula* are apparently the same today as they were in the Silurian period *estimated at about 25 million years ago*," that *Turrilites costatus* is an "*uncoiled* ammonite," or that "*Triarthrus becki* occurs in the Utica shale (*Lower Silurian*)." Nor will all zoologists and paleontologists be in complete agreement with Hegner's arrangement of the phyla "according to their supposed position in the evolutionary series."

But these are details, and the reviewer recommends that this text, or the more advanced *Invertebrata* by Borradaile and Potts, be added to the reference works of serious students of invertebrate paleontology.

CAREY CRONEIS

Vertebrate Paleontology. By ALFRED SHERWOOD ROMER. Chicago: University of Chicago Press, 1933. Pp. vii+491; figs. 359. $3.00.

A comparison of the content of this book with that of an earlier work by A. Smith Woodward clearly emphasizes the remarkable progress made

in vertebrate paleontology in the acquisition of additional information during the past three decades. The subject matter treated in the chapters relating to particular groups of fossil vertebrates is proportioned approximately as in the *Outlines of Vertebrate Palaeontology*. Those chapters dealing with the jawless vertebrates and fishes are relatively shorter, although new material acquired in these fields has not been omitted. Increase in our knowledge of number and type of the higher chordates is particularly evident in the discussion of the reptiles and mammals, less so in the case of the amphibia. Judged in this light, we may conclude from the chapter on birds that no comparable advance has been made in the history of these forms.

The text is written largely from the standpoint of the student in biology interested in the structural characters of fossil vertebrates and in the relationships known or assumed to prevail between extinct and existing forms. In the introductory chapter divers matters are briefly considered; namely, the preservation of vertebrate fossils, the geologic time scale, evolution theories, classification, and vertebrate structure and ancestry. The following chapters afford an appreciation of the ofttimes amazing variety to be found among fossil vertebrates and include statements of the more important morphological and adaptive characters of these and of representative living types. Charts show clearly the distribution of groups in time and phylogenetic trends. The text probably will be found to serve best as a general introduction to vertebrate paleontology. The general reader, moreover, will doubtless find much of absorbing interest in this recounting of the facts of the fossil record. Doubtless the limitations of space did not allow more of the geological background to be woven into the discussion. Brief statements of the occurrence of the more important fossils with citations of specific localities in many instances might have rendered the book even more useful to the student making his approach through historical geology.

A synoptic classification of vertebrates and a very useful bibliography are included. Under the latter I find, however, no mention of the contributions by Loye Miller on fossil birds. The illustrations, of which there are many, have been executed in excellent manner.

CHESTER STOCK

The Principles of Historical Geology from the Regional Point of View. By RICHARD M. FIELD. Princeton University Press, 1933. Pp. xii + 283; figs. 108; Pl. 10. $3.50.

This book on historical geology may mark an epoch in the teaching of historical geology like that made by the Harvard Law School when they

introduced the case system in the teaching of law; for this book, after twenty-two pages on the history of the development of stratigraphic geology and sixty pages of general description of the principles, has for its main part the description of certain geological provinces arranged so that they may bring out in concrete examples the application of these principles and the method by which their stratigraphy has been interpreted. Wisely the author has chosen regions which would naturally be visited by the traveler: the Grand Canyon region, Niagara Falls, a region in the Appalachians of Pennsylvania, the Northwest Highlands of Scotland, the Alps, and the Yellowstone.

The book is quite as much a contribution to the history of science, and particularly to the history of geology, as to the teaching of historical geology, for every section begins with a general introduction giving some account of the appeal of the region to anyone and also a historical account of the development of knowledge of the geology. In that way the various chapters may be considered as geological guides to the various regions visited. If used for that purpose, however, there are many unusual terms not found in the standard dictionaries which would be a hindrance to the general reader. It is avowedly intended as a second course in historical geology after a first course has definitely given some of these terms.

There are so many of these new terms that when, as for instance, one meets a misprint, as on page 5, "*Angeschwemmigebirge*" for "*Angeschwemmtgebirge*," one has to stop and wonder whether it is really a misprint or a new term. There is a slip of misprints available. The reviewer, finding "Salona" on the same page as "Silurian," at first thought that "Salina" was intended! In some of the earlier geological reports it was customary to have at the end a small glossary of the scientific terms and one is not sure whether it might not be well in some of our newer texts to adopt the plan of having at the end a glossary of terms not found in the standard dictionaries.

It is gratifying to the reviewer to see the work of Grabau so much used and appreciated.

The Index at the end, however, does not contain the names of the various formations, and so, for instance, when one finds a reference to the Tonto sandstone, "of Proterozoic age" [*sic*] on page 180, he does not know where to look to find its exact relation in the stratigraphy of the Grand Canyon, in the formal section of which, on page 92, it is not given. In Figure 47 it is classed as Paleozoic.

Realizing that much of fact may be taught in the first course in historical geology which will soon be forgotten by the average student or questioned by the research geologist, Dr. Field has made a most interesting de-

parture from the practice of stating all details as conclusive facts as found in the conventional textbook, and a main general impression of the book is that there are yet interesting questions in geology which the reader can help to solve. This is a very distinct advantage. It is also refreshing to find a geologist who appreciates beauty in nature and who does not hesitate to write about it. Geologists visiting the classical regions described in the book should not fail to note such beauty.

There are, furthermore, a number of new and excellent block diagrams, but some indication of scale and the latitude and longitude would add to their value.

It must be kept clearly in mind that this book is mainly written upon the stratigraphic side and the story of life and organic evolution have but scanty treatment. It should be a help in teaching historical geology, and even when some other text is used, as stimulating collateral reading should be of great value.

ALFRED C. LANE

Stream Sculpture on the Atlantic Slope: A Study in the Evolution of Appalachian Rivers. By DOUGLAS JOHNSON. New York: Columbia University Press, 1931. Pp. 142+xxii; figs. 21. $3.25.

Professor Johnson's theory of regional superposition, presented in this volume, offers a new interpretation of the complicated history of the Appalachian highlands. In its essentials the theory involves a pre-Schooley (pre-Kittatinny) peneplane extending over the highlands, with a cover of coastal-plain deposits resting on this old surface, and extending to the northwest over the Appalachian folds. These two elements include the key to the interpretation of the physical history of the region. The evidence for his theory is presented by Dr. Johnson in a compelling and convincing manner.

The author first reviews several accepted principles of Appalachian geomorphology, and follows them with a statement of his theory of regional superposition. The nine block diagrams which are included to show the successive stages in the physical history of the region are an excellent supplement to the text.

The new theory explains the development of the present master streams from courses inherited from the old coastal-plain cover. While these views differ from previous explanations, readers of the volume will agree that in the clear presentation of his evidence Dr. Johnson carries his points to conviction. In connection with a discussion of the implications of his

theory, the author offers his new interpretations of the drainage development of Pennsylvania and northern New Jersey.

The book contains a Foreword by Dr. W. M. Davis. It is amply and clearly illustrated. The volume cannot fail to attract the attention of students of geomorphology.

W. C. KRUMBEIN

Soils, Their Origin, Constitution, and Classification: An Introduction to Pedology. By GILBERT WOODING ROBINSON. London: Thomas Murby & Co., 1932. Pp. xv+390; figs. 13. 20/–net.

In this book the emphasis is upon the study of soil as such, with less direct consideration of the economic aspects.

After an introductory chapter, seven chapters are devoted to the constitution, origin, and properties of soils. In the six following chapters are descriptions of the principal soil groups of the world. The last five chapters are given to a discussion of systems of classification, geographical distribution of soil types, soil surveys, soil analysis, and finally the interrelationships of the soils, plant growth, and agriculture. In the Appendix, which describes methods of analysis, chief attention is given to procedures of mechanical analysis. All of the chapters are supplied with bibliographies which give a good introduction to the field. It is difficult to select outstanding chapters because of the uniform high quality of the book. The introductory chapters and those discussing pedogenic processes, the clay complex, water relationships of soils, and classification of soils may be of particular interest to geologists.

Certain views that are presented should be mentioned. Although not minimizing the necessity of laboratory tests, the author emphasizes the importance of a greater amount of field study with more complete observations based upon the soil profile as the unit of study. In the development of world soil types climate is believed to be the dominant factor, while the nature of the underlying rock and the topography are important in regions of transition and in the smaller units of classification. Throughout the discussion of the formation of clay, kaolinite is held to be dominantly of pneumatolytic, rather than of epigene, origin. The work of Ross and Kerr, published in 1931, would throw doubt upon this view.

EDWARD L. TULLIS

Principles and Practice of Geophysical Prospecting. By A. B. BROUGHTON EDGE and T. H. LABY. London: Cambridge University Press, 1931. Pp. 372; figs. 216.

This report of the Imperial Geophysical Experimental Survey describes tests made of several geophysical methods in economic geological exploration under various Australian field conditions.

Electrical exploratory methods in general were found to be useful to depths of 300 feet. The equipotential line method is recommended in prospecting for metalliferous deposits of normal lode or lenticular shape. Resistivity measurements are useful in investigations of the ground-water table and of structure. Further work, the authors believe, may lead to effective utilization of alternating current potential ratio measurements. The results, however, seem to indicate that magnetic exploratory methods are to be used only for shallow depths.

Gravimetric data obtained compare very favorably with data secured from bore holes. Seismic methods are considered to be only moderately accurate and require the most favorable conditions.

The authors have been conservative in their evaluation of the various geophysical prospecting methods. The book contains a valuable collection of data from which further research can be projected.

RANDALL WRIGHT

A French-English Vocabulary in Geology and Physical Geography. By G. M. DAVIES. London: Thomas Murby & Co.; New York: D. Van Nostrand Co., 1932. Pp. ix+140. 6*s*.

This much-needed work fills a gap in technical dictionaries by supplying those common words which are used in a semi-technical sense. Words which are self-explanatory and those whose technical meaning is alike in the two languages are omitted. Widely used stratigraphical terms are included and the Appendix gives, in tabular form, Continental European stratigraphic terms and their English equivalents. The book should be of value to English-speaking geologists who have occasion to refer frequently to French publications.

H. W. STRALEY, III

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